

Inclusive search for same-sign dilepton signatures in pp collisions at $\sqrt{s} = 7$ TeV with the ATLAS detector

ATLAS collaboration

ABSTRACT: An inclusive search is presented for new physics in events with two isolated leptons (e or μ) having the same electric charge. The data are selected from events collected from pp collisions at $\sqrt{s} = 7$ TeV by the ATLAS detector and correspond to an integrated luminosity of 34 pb^{-1} . The spectra in dilepton invariant mass, missing transverse momentum and jet multiplicity are presented and compared to Standard Model predictions. In this event sample, no evidence is found for contributions beyond those of the Standard Model. Limits are set on the cross-section in a fiducial region for new sources of same-sign high-mass dilepton events in the ee , $e\mu$ and $\mu\mu$ channels. Four models predicting same-sign dilepton signals are constrained: two descriptions of Majorana neutrinos, a cascade topology similar to supersymmetry or universal extra dimensions, and fourth generation d -type quarks. Assuming a new physics scale of 1 TeV, Majorana neutrinos produced by an effective operator V with masses below 460 GeV are excluded at 95% confidence level. A lower limit of 290 GeV is set at 95% confidence level on the mass of fourth generation d -type quarks.

KEYWORDS: Hadron-Hadron Scattering

Contents

1	Introduction	1
2	Description of the ATLAS experiment	2
3	Physics simulation data	3
4	Sample selection and Standard Model sources	3
4.1	Sample selection	4
4.2	Sources of same-sign dileptons in the Standard Model	5
4.3	Characterisation of Standard Model sources	5
5	Systematic uncertainties	8
6	Consistency of observation with the Standard Model	9
7	Limit on generic same-sign high-mass dilepton production	10
8	Limits on specific models	13
8.1	Majorana neutrinos	14
8.2	Lepton cascades	16
8.3	Heavy down-type quarks	20
9	Conclusion	20
	The ATLAS collaboration	25

1 Introduction

A diverse group of models predict interactions producing two isolated leptons of the same electric charge and with significant transverse momentum — a signature quite rare in the Standard Model (SM). An inclusive search for such processes recorded by ATLAS is presented for the first time at a centre-of-mass energy $\sqrt{s} = 7$ TeV. Events with a same-sign dilepton (ee , $e\mu$, $\mu\mu$) signature were selected from pp collisions produced by the LHC with an integrated luminosity of 34 pb^{-1} .

The ATLAS collaboration has performed a dedicated search for supersymmetric phenomena [1] in events with exactly two leptons and large missing transverse momentum selected from the same pp collision data described herein. By contrast, the inclusive analysis described in this article presents model-independent limits from events that may have more than two leptons and no missing transverse momentum. The CMS collaboration has searched for new phenomena in same-sign dilepton events with jets and missing transverse

momentum [2]. Inclusive analyses by the CDF collaboration present kinematic distributions and 95% confidence limits using up to 1 fb^{-1} of $p\bar{p}$ collisions [3, 4] at a centre-of-mass energy of 1.96 TeV. The CMS and CDF collaborations searched for fourth-generation d -type quarks in 34 pb^{-1} of pp collisions [5] and in 2.7 fb^{-1} of $p\bar{p}$ collisions [6], respectively. They set lower mass limits of 361 GeV and 338 GeV respectively, at 95% confidence level. A search by the DØ collaboration excludes a right-handed W boson W_R with mass less than 739 GeV in left-right symmetric models (LRS) [7]. Various other specific searches have been performed in same-sign dilepton samples by these experimnts [8–11].

In this article, spectra in dilepton invariant mass ($m_{\ell\ell}$), jet multiplicity (N_{jets}), and missing transverse momentum ($E_{\text{T}}^{\text{miss}}$)¹ are studied for consistency with the SM or evidence for new physics. The SM prediction is estimated mainly by extrapolation from control samples selected in the data. Additional small contributions are determined using simulated events. In a kinematic fiducial region, an upper limit on the cross-section of high-mass ($m_{\ell\ell} > 110 \text{ GeV}$, above the Z -mass region) same-sign dilepton events from non-SM sources is given for each channel, and benchmark selection efficiencies for some specific models are provided. In the subsample of events with at least one jet, a number of limits are set: first limits on the mass of Majorana neutrinos in an effective operator framework [12], and limits surpassing previous experimental results [13, 14] in an LRS scenario [15]. This sample is also interpreted to set cross-section limits on a cascade topology found in supersymmetry and models with universal extra dimensions (UED) [17] in terms of masses of the minimally required particles. Using the subsample with $E_{\text{T}}^{\text{miss}} > 30 \text{ GeV}$, a lower limit on the mass of a fourth generation down-type quark (d_4) [18] is obtained.

2 Description of the ATLAS experiment

The ATLAS detector [19] is a multipurpose detector of charged and neutral particles with precision trackers, calorimeters and muon spectrometers. The momenta of charged particles with pseudorapidity $|\eta| < 2.5$ ² are measured by the inner detector (ID), which is a combination of a silicon pixel detector, a silicon microstrip detector and a straw-tube detector. The ID operates in a uniform 2 T magnetic field. The pixel detector measurements notably enable precise determination of production vertices.

Electromagnetic calorimetry for electron, photon, and jet reconstruction is provided by a high-granularity, three depth-sampling liquid-argon (LAr) detector with lead absorbers in the region $|\eta| < 3.2$. Jet reconstruction also uses hadron calorimetry provided by a scintillating tile detector with iron absorbers in the central region for $|\eta| < 1.7$, and a LAr

¹The missing transverse momentum in an event, denoted $E_{\text{T}}^{\text{miss}}$, is the vector difference between zero and the total transverse momentum, calculated from energy depositions in the calorimeter and momentum measurements from the muon spectrometer for identified muons.

²ATLAS uses a right-handed coordinate system with its origin at the nominal interaction point (IP) in the centre of the detector and the z -axis along the beam pipe. The x -axis points from the IP to the centre of the LHC ring, and the y axis points upward. Cylindrical coordinates (r, ϕ) are used in the transverse plane, ϕ being the azimuthal angle around the beam pipe. The pseudorapidity is defined in terms of the polar angle θ as $\eta = -\ln \tan(\theta/2)$.

detector for $1.5 < |\eta| < 4.9$. A presampler detector is used to correct for energy lost by electrons and photons in material in front of the calorimeter for $|\eta| < 1.8$.

Dedicated muon reconstruction is performed by a multi-system muon spectrometer (MS). Precision measurements in the η coordinate are provided by measurements of monitored drift tubes for $|\eta| < 2.7$. These are supplemented by cathode-strip chambers measuring both the η and azimuth (ϕ) coordinates for $2.0 < |\eta| < 2.7$ in the innermost endcap muon station. Fast measurements required for initiating trigger logic are provided by resistive-plate chambers for $|\eta| < 1.05$, and beyond that by thin-gap chambers to $|\eta| < 2.4$. The muon detectors operate in a non-uniform magnetic field generated by three superconducting air-core toroid magnetic systems.

To trigger readout, full event reconstruction and event storage by the data acquisition system, at least one electron or muon candidate is required that satisfies the following criteria. Electron candidates must have transverse energy $E_T > 15$ GeV.³ They must satisfy shower-shape requirements⁴ and correspond to an ID track. Muon candidates must have transverse momentum $p_T > 13$ GeV, $|\eta| < 2.4$, and a consistent trajectory reconstructed in the ID and MS. The full trigger chain uses signals from all muon detectors.

3 Physics simulation data

The response of the ATLAS detector is simulated [21] using GEANT4 [22]. The parameter settings for the Monte Carlo programs are described in ref. [23]. The Z and W events were generated using ALPGEN v2.13 [24] with the CTEQ6L1 parton distribution function (PDF) set [25]; WW , WZ , and ZZ events using HERWIG 6.510 [26–28] with the MRST2007 LO* PDF set [29]; $Z\gamma$ and $W\gamma$ events using MADGRAPH v4 [30] with the CTEQ6L1 PDF set, interfaced to PYTHIA 6.421 [31]; and $t\bar{t}$ events using MC@NLO 3.41 [32, 33] with the CTEQ6.6 PDF set [25], interfaced to HERWIG. Cross-sections for $t\bar{t}$ events are calculated at approximate next-to-next-to-leading order [34], at next-to-next-to-leading order for events with a boson and jets, and at next-to-leading order for diboson events.

4 Sample selection and Standard Model sources

In this article *same sign dilepton event* refers to a pp interaction that produces two leptons (e or μ) with matching electric charge, where both leptons are produced promptly by the primary interaction. Such prompt leptons will usually be isolated from hadronic jets in the event. Leptons from hadron decays, for example from hadrons with b or c quarks, are classified as background in this analysis, along with instrumental background. Various selection criteria are applied for background suppression.

³During early data-recording periods, trigger momentum thresholds for electrons and muons were sometimes lower, with minimum values of 10 GeV, combined with other minor algorithmic differences. However, the efficiencies for events entering the selected samples from these periods, representing 10% of the sample for electrons and 20% for muons, are not significantly different.

⁴The medium selection defined in section 4.2 of ref. [20] is used.

4.1 Sample selection

The sample includes events having at least two lepton candidates within the experimental acceptance. Each must pass a tight type-identification and track quality selection and an isolation condition that rejects leptons within jets; these requirements are described below. Each lepton candidate is required to have p_T greater than 20 GeV. For muons, the transverse momentum measurement uses information from both the ID and MS. An isolation requirement on nearby calorimeter depositions is applied: the sum of transverse-energy depositions not associated with the candidate within a cone of radius $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} = 0.2$ surrounding the candidate lepton must be less than 15% of the lepton E_T . To control relative efficiencies among samples, the data acquisition system must have been triggered by at least one of the two isolated leptons in the same-sign pair.

A number of requirements ensure the quality of particle tracks and type-identification. Candidates for the main electron sample are *tightly selected*: they are identified by calorimeter cluster properties and matched to a track in the η and ϕ coordinates, with the same criteria used for the trigger. They are reliably reconstructed in the region $|\eta| < 2.47$, except in the barrel-endcap transition region $1.37 < |\eta| < 1.52$ which is excluded. Electron candidates must have a calorimeter energy to track momentum ratio E/p consistent with expectations for an electron. The precise values vary with $|\eta|$ and p_T ; for electrons with $\eta = 0$ and $p_T = 50$ GeV, we require $0.7 < E/p < 5.0$. If a track trajectory passes through an active region of the innermost pixel layer, a measurement in that layer is required for suppression of electrons from photon conversions. Electron candidates from tracks that are also reconstructed as viable muon candidates are rejected.

Candidates for the tightly selected muon sample are selected from tracks reconstructed in the MS and matched to tracks in the ID. The two measurements of the track parameters are then combined [35]. Candidates are accepted in the range $|\eta| < 2.5$. Charge measurements made by the ID and MS must agree.

Electron and muon control samples are also used to study the properties of lepton candidates likely to be found in misreconstructed events in the same-sign dilepton sample. These samples are defined in the description of the background prediction method.

Jets are reconstructed and used in three ways: to define jet multiplicity, an important feature of some predicted signals; to reject isolated muons from b -flavoured jets; and to select a control sample of events with electrons originating from semileptonic hadron decays. All jets in this analysis are defined by the anti- k_t algorithm [36, 37], with radius parameter equal to 0.4, applied to calorimeter clusters [38]. To be counted in jet multiplicity, jets must have $p_T > 30$ GeV and $|\eta| < 2.5$. For rejection of muons from b -jets, a looser requirement of $p_T > 20$ GeV is made. Muons are rejected within a cone of $\Delta R = 0.4$ around such jets. For selecting events for the electron control sample, all jets reconstructed within the experimental acceptance are considered.

For inclusion in the dilepton event sample, the two lepton candidates must originate from the same primary vertex; this primary vertex must contain at least five tracks to suppress non-collision events.

4.2 Sources of same-sign dileptons in the Standard Model

In the SM, events with the same-sign dilepton signature may be produced in three ways: events containing two gauge bosons, events in which a lepton originates in a jet, and events in which the reconstructed charge of a lepton is not that produced in the primary interaction.

True same-sign dilepton events are produced from SM diboson processes, most notably WZ processes. These are a rare but irreducible background to new physics sources, since events with more than two leptons are not excluded by the selection. They are distinguishable from new sources only by differences in kinematic spectral shapes.

The main SM background categories are sources that enter the sample due to misreconstruction of the event, i.e., a selected lepton candidate is not a primary product of the main interaction. Jets often produce leptons that are wrongly reconstructed as primary. As well, the charge of a selected lepton candidate may not be the primary charge from the interaction.

When an event is selected for the sample using a lepton candidate from a jet, this lepton is called a *flavour fake* (denoted by the term “QCD” in plots and symbols). This is because the lepton originates from a hadronic jet, so the observed lepton flavour does not reflect the primary interaction process. Processes that are often reconstructed as same-sign dileptons in this way are dijet processes and final states with a W boson and jets. This is the main background considered in this analysis as it has the largest overall contribution to the sample. It is dominant in the $\mu\mu$ and $e\mu$ channels.

It is also possible to misreconstruct an event as same sign if final state particles produced with opposite electric charge lead to good same-sign lepton candidates in the detector. Processes susceptible to this effect are $Z/\gamma^* \rightarrow e^+e^-$ and $t\bar{t}$ semileptonic decays with at least one electron. This misreconstruction occurs if an electron undergoes bremsstrahlung, and upon conversion the photon passes the larger share of momentum to an electron of the opposite charge. For this reason, this effect is called *electron charge flipping* (denoted by “charge flip” in plots). The charge-flip category is large in the ee channel and present in the $e\mu$ channel. When the bremsstrahlung does not carry the majority of the electron energy, misidentification of electron charge may occur due to misreconstruction of the ID track. If found in this analysis, such events would be included in the charge-flip category. Due to the near absence of photons converting to muon pairs, this category does not appear in the $\mu\mu$ channel. Muon charge misidentification is negligible over the range of p_T found in the sample.

4.3 Characterisation of Standard Model sources

The data are used to characterise the background from misreconstruction, especially flavour fake events. The rates of heavy flavour dijet events are not well known *a priori*, and so would suffer from substantial uncertainties if derived purely from simulation. Instead a method, described in the following, is used which extrapolates from control samples to the signal region. The control samples are separate samples of background electrons and muons,

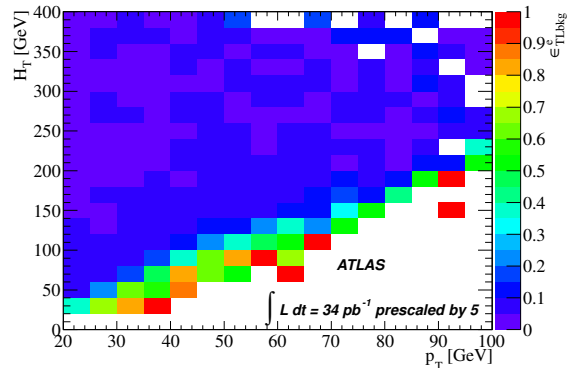


Figure 1. The selection efficiency for candidates mimicking primary electrons, $\epsilon_{\text{TLbkg}}^e$, defined as the fraction of loosely selected electrons that also pass tight selection, measured in an enriched background sample of recorded data and parameterised in p_T and H_T to demonstrate the dependence. The events used to determine $\epsilon_{\text{TLbkg}}^e$ were recorded using a photon trigger, which was prescaled for part of the 2010 pp data collection. Empty regions (white) are either kinematically impossible ($H_T < p_T$) or unpopulated.

from events that have fewer than two reconstructed leptons and therefore are independent of the main sample. The procedure is discussed in detail below.

To examine the properties of background events, a *loosely selected* sample of electron candidates is defined with relaxed selection criteria, by removing the isolation and E/p requirements, while loosening shower-shape and track quality requirements⁵ to allow sufficient statistics across the relevant phase space. The tightly selected electron sample is therefore a subset of the loosely selected sample. To predict the kinematic distributions of misreconstructed events, dielectron events are chosen that have two same-sign electrons in the loosely selected sample. These events are classified into components depending on whether the loosely selected electrons also pass tight selection: (1) both are tightly selected, (2) only one is tightly selected, or (3) neither is tightly selected.

By applying measured efficiencies as event weights, these yield components may be transformed into isolated dielectron and background yield components. The transformation is expressed by a system of linear equations [39] that project the true primary dilepton and background category yields from the loose and tight categories. The projection to component yields relies on the assumption that the flavour fake rate found in enriched background samples described below is applicable to the flavour fakes in dilepton events.

The selection efficiency for candidates mimicking primary electrons, $\epsilon_{\text{TLbkg}}^e$, is defined as the fraction of loosely selected electrons that also pass the tight selection. The enriched background sample used to measure $\epsilon_{\text{TLbkg}}^e$ is characterized by events with at least one lepton from a jet, implemented by requiring a unique loosely selected electron in the event. The events in this sample were accepted by a photon trigger defined by a subset of the loose electron selection rules [40]. To further select events with leptons from semileptonic hadron decays, which are produced in jets, the E_T^{miss} and any adjacent jet axis must have

⁵The loose selection defined in section 4.2 of ref. [20] is used.

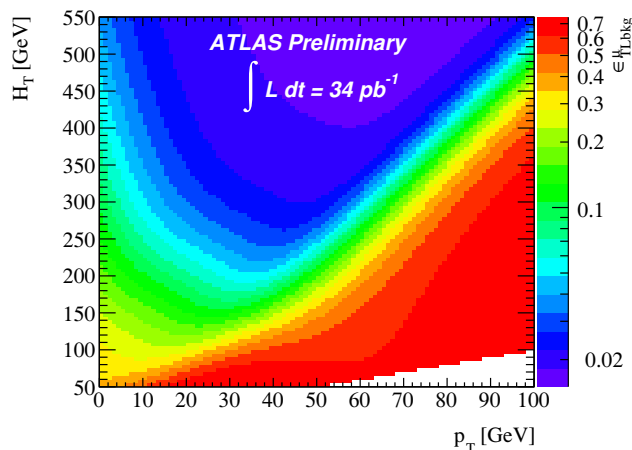


Figure 2. The selection efficiency for candidates mimicking primary muons, $\epsilon_{\text{TLbkg}}^{\mu}$, defined as the fraction of loosely selected muons that also pass tight selection, parameterised as a function of p_{T} and H_{T} to demonstrate the dependence. Empty regions (white) are kinematically impossible ($H_{\text{T}} < p_{\text{T}}$).

a maximum azimuthal difference of $\Delta\phi(E_{\text{T}}^{\text{miss}}, \text{jet}) < 0.1$. This sample is therefore mostly composed of dijets. Possible bias in the measured efficiency due to the event selection is included in the systematic uncertainty, described in section 5. The background efficiency $\epsilon_{\text{TLbkg}}^e$ is measured separately for electrons which satisfy the electron trigger requirement and for those which do not, and is parameterised by p_{T} of the electron and H_{T} , defined as the sum of E_{T} over all reconstructed objects in the event (figure 1). For relatively rare dijet events in which H_{T} has a large contribution from the electron candidate itself, the electron candidate is likely to satisfy the isolation requirement due to the lack of non-associated energy depositions nearby; this correlation is described by the diagonal band in figure 1.

To study true primary electrons, dielectron events with one tightly selected and one loosely selected electron, of opposite charge, are selected to form an enriched electron sample of $Z \rightarrow e^+e^-$ events, requiring $86 < m_{e^+e^-} < 96$ GeV to achieve a high purity. The loosely selected electron is checked for inclusion in the tightly selected sample to measure the relative efficiency between the tight and loose selection rules.

A fraction of the charge-flip electron background is included in the described data-driven procedure. However, studies of Z events show that electron charge-flips are well modeled, so this category is instead described with simulated data and the overlap is subtracted from the data-driven background prediction to isolate the flavour fake prediction. The charge-flip overlap fraction is measured by normalizing the simulated prediction to the observed reflection peak from $Z \rightarrow e^+e^-$ processes and found to be $(19 \pm 16)\%$. Simulation data scaled to the recorded luminosity are added to the predicted flavour-fake distributions. The diboson background contribution is taken from simulation.

Muons are treated similarly, with $\epsilon_{\text{TLbkg}}^{\mu}$ parameterised in the p_{T} of the candidate and H_{T} (figure 2). The $\epsilon_{\text{TLbkg}}^{\mu}$ is fit using a Bayesian neural network [41–43] to extract

	n_{obs}	n_{pred}	n_{fake}	$n_{\text{charge-flip}}^{\text{sim}}$	$n_{\text{diboson}}^{\text{sim}}$
ee	10	$21.8 \pm 9.4 \pm 3.8$	$11.1 \pm 9.4 \pm 2.8$	$10.1 \pm 0.9 \pm 2.5$	$0.6 \pm 0.0 \pm 0.1$
$\mu\mu$	9	$6.1 \pm 2.8 \pm 1.2$	$4.8 \pm 2.8 \pm 1.2$	—	$1.3 \pm 0.0 \pm 0.1$
$e\mu$	25	$17.5 \pm 9.3 \pm 3.7$	$15.0 \pm 9.3 \pm 3.7$	$0.5 \pm 0.2 \pm 0.1$	$2.1 \pm 0.0 \pm 0.2$

Table 1. The observed (n_{obs}) and predicted (n_{pred}) yields of same-sign dilepton events. The prediction is the sum of the individual estimates of the number of events with misreconstructed flavour (n_{fake}), the number of events with misreconstructed charge ($n_{\text{charge-flip}}^{\text{sim}}$), and the number of true SM same-sign dilepton events ($n_{\text{diboson}}^{\text{sim}}$). Uncertainties are statistical followed by systematic. The dominant statistical errors are due to the small number of events in the background control samples from which the misreconstructed flavor background predictions are calculated. The dominant systematic uncertainties are due to uncertainty on the method of misreconstructed flavor background calculation, see table 2 and text in section 5. The $Z \rightarrow ee$ peak is suppressed by excluding events with $80 < m_{ee} < 95$ GeV. The electron charge-flip category does not apply to the dimuon channel; this is indicated by a dash in the table.

a smooth functional dependence. The loose muon selection is defined by removing the isolation requirement from the tight selection rules. A flavour fake sample of muon events is defined with a unique loosely selected muon and a requirement that the invariant mass of this muon with the event $E_{\text{T}}^{\text{miss}}$, must not exceed 30 GeV in the transverse plane. The Bayesian neural network is trained on this sample and used exclusively to describe the shape of the flavour fake efficiency distribution as a function of p_{T} and H_{T} . The selection efficiency for primary muons to appear in the tightly selected sample relative to the loosely selected sample is approximately unity, as found in studies of $Z \rightarrow \mu\mu$ events. As with the dielectrons, a linear transformation is made to the true primary dimuon and background components.

An event sample of same-sign $e\mu$ dilepton events is analyzed for component yields using the same prescription with the measured efficiencies for electron and muon selection already described.

The event yields and contributions of the various background categories are presented in table 1. The observed yields are consistent with Standard Model predictions, and this is quantified in section 6. The dominant source of uncertainty in the prediction is the statistical uncertainty of the yield of flavour fake events. This statistical uncertainty is relatively large because of the small number of leptons in the background control samples from which these predictions are calculated.

5 Systematic uncertainties

The largest source of systematic uncertainty is the weighting of events to extract yield predictions for signal and background. Two studies quantify the overall magnitude of this uncertainty. In the first, $c_{\text{TLbkg}}^{e,\mu}$ is measured in simulated data with known generated properties. In the second, $c_{\text{TLbkg}}^{e,\mu}$ is used to predict the number of events with a flavour fake in the region $10 < p_{\text{T}} < 20$ GeV for the less energetic lepton of the pair, where flavour fakes

Source of uncertainty	Size
Data-driven predictions	
Category transformation, yield and shape	25% of yield
Monte Carlo predictions	
Luminosity	3.4% of yield
Jet-energy calibration	$\leq 2\%$ of yield
E/p requirement ($E_T^e < 150$ GeV)	3% of ϵ^e
E/p requirement ($E_T^e \geq 150$ GeV)	12% of ϵ^e
Electron charge misidentification	1.5% of ϵ^e
Muon momentum resolution	$< 1\%$ of ϵ^μ
Electron energy resolution	$< 1\%$ of ϵ^e

Table 2. Sources and estimated sizes of systematic uncertainties, for data-driven predictions and for Monte Carlo predictions of background and hypothetical signals, shown as a fraction of the event yield or of the electron and muon efficiencies (ϵ^e and ϵ^μ , respectively).

are expected to be dominant. This study tests the reliability of both the parameterisation and use of $\epsilon_{\text{TLbkg}}^{e,\mu}$ for predictions of events where both leptons come from jets. Both studies indicate a 25% uncertainty. Other systematic uncertainties are much smaller and affect predictions of signal and background from simulations. The integrated luminosity of the sample is known with an uncertainty of 3.4% [44, 45], and the uncertainty on the jet-energy calibration [38] yields an uncertainty of less than 2% on the yields in this sample. The uncertainty on the measured electron efficiency is dominated by the uncertainty of the E/p distribution. This uncertainty is estimated as the difference between electron efficiencies measured in simulated and recorded e^+e^- events; this yields a 3% uncertainty on the efficiency for E_T below 150 GeV, for which there are many recorded electrons, and a 12% uncertainty for $E_T > 150$ GeV, for which there are few recorded events. The uncertainty on the electron efficiency from electron-charge misidentification is determined by comparing simulated and recorded same-sign $Z \rightarrow ee$ events, and is found to average 1.5%. Efficiency uncertainties due to momentum or energy resolution are less than 1%. A comparison of systematic effects is given in table 2. We conclude that the sensitivity of this analysis is predominantly affected by the accuracy of the data-driven background predictions, and is largely unaffected by uncertainties arising from the use of simulated samples.

6 Consistency of observation with the Standard Model

A validation of the SM prediction is made in samples of opposite-sign dilepton events. The $e\mu$ channel is the most suitable for validation because it contains both lepton flavours, and comparable contributions from data-driven methods and simulation. The contribution from $Z \rightarrow \tau\tau$ decays is relatively small. The results of this validation are shown in figure 3, with component categories indicated. As shown, there is good agreement (within the combined statistical and systematic uncertainty) between the observed data and the prediction in most bins of the kinematic distributions.

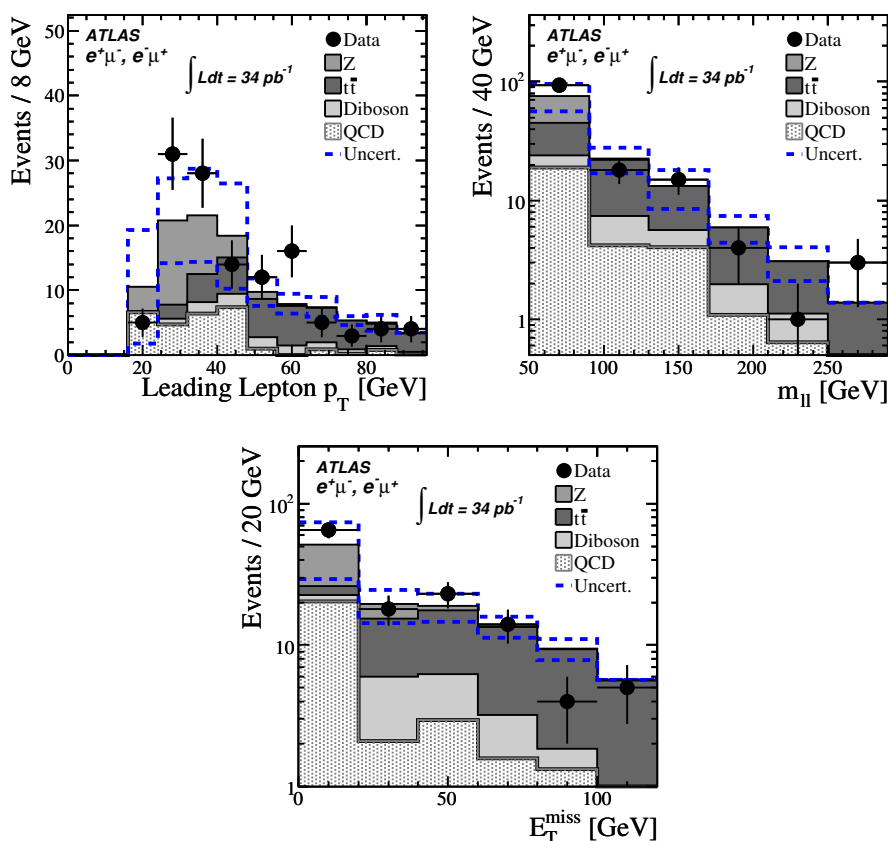


Figure 3. Validation of the SM prediction method in the opposite-sign $e\mu$ channel. Kinematic variables are shown: p_T of the leading lepton (top left), $m_{\ell\ell}$ (top right) and E_T^{miss} (bottom). Statistical and systematic uncertainties on the prediction are shown as a dashed blue line. Overflow events are included in the highest bin. The contribution labeled Z is dominated by $Z \rightarrow \tau\tau$ decays but includes a small contribution from $Z \rightarrow \mu\mu$ decays where a hard photon is radiated from a muon, converts and is reconstructed as an electron.

The SM predictions in the same-sign samples are reported in table 1. The observed and predicted kinematic distributions are shown in figures 4 and 5. The consistency between the shape of the observed and predicted distributions is evaluated with a Kolmogorov-Smirnov (KS) distance test [49]. Agreement is found between the observed data and the SM prediction, as shown in table 3. Dielectron events in the region $80 < m_{\ell\ell} < 95$ GeV are excluded in the analysis of the E_T^{miss} and N_{jets} distributions to suppress contamination from misreconstructed $Z \rightarrow ee$ events.

7 Limit on generic same-sign high-mass dilepton production

Beyond the charge-flip reflection of $Z \rightarrow ee$ (see figure 4, left), the $m_{\ell\ell}$ spectrum is sensitive to the presence of new sources of same-sign dilepton events. In the domain $m_{\ell\ell} > 110$ GeV, $8.5 \pm 3.8_{(\text{stat})} \pm 0.7_{(\text{syst})}$ events are predicted by the SM, primarily in the flavour-fake category. Four events are observed.

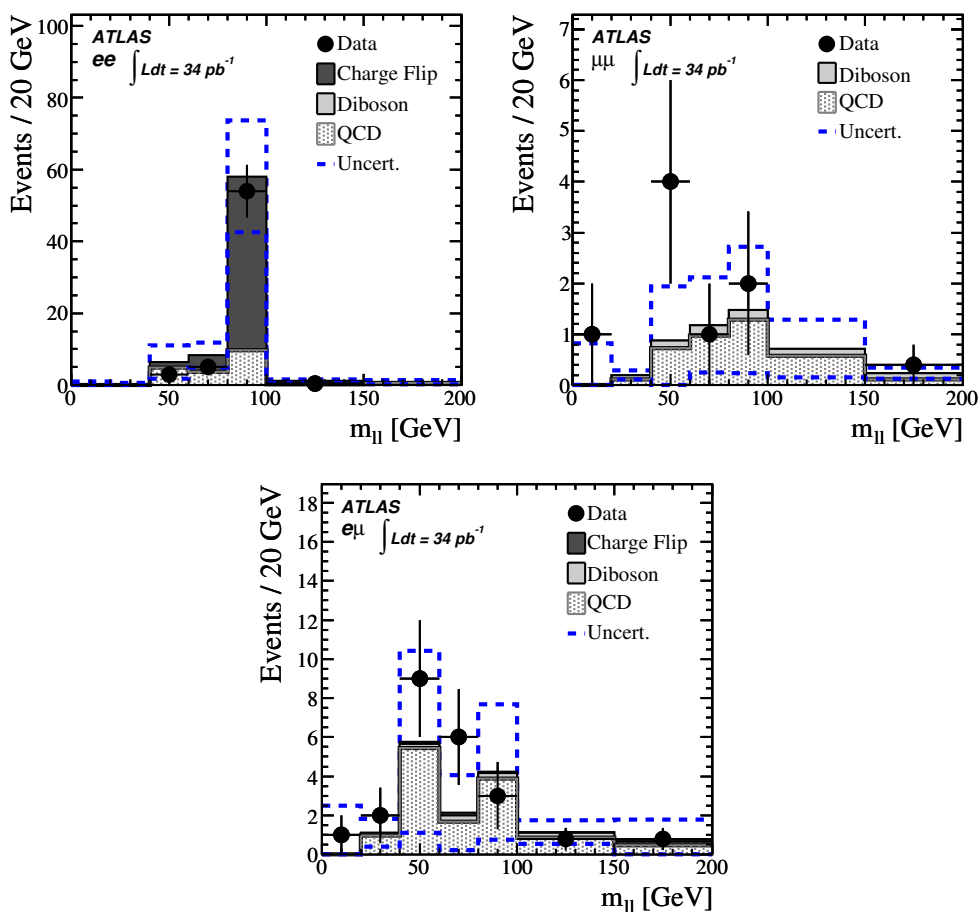


Figure 4. Distributions of same-sign dilepton invariant mass in the ee (top left), $\mu\mu$ (top right) and $e\mu$ (bottom) channels. Shown are data (points) and backgrounds (solid stacked histograms). The combined statistical and systematic uncertainty is shown as a dashed blue line. Overflow events are included in the final bin.

Distribution	ll	ee	$\mu\mu$	$e\mu$
m_{ll}	0.15 (84%)	0.33 (36%)	0.60 (28%)	0.40 (43%)
$m_{ll} > 110$ GeV	0.54 (23%)	1.00 (7%)	0.76 (34%)	0.19 (91%)
E_T^{miss}	0.19 (72%)	0.60 (11%)	0.39 (59%)	0.36 (50%)
N_{jets}	0.18 (73%)	0.59 (12%)	0.37 (57%)	0.28 (59%)

Table 3. Results of KS-distance test between data and Standard Model predictions. The maximum KS distance and corresponding p -value (in parentheses) is given for three kinematic distributions presented in this analysis (figures 4 and 5), and one high-mass subset. Statistical and systematic fluctuations are included in the p -value calculation. We find agreement between the observed data and the SM prediction.

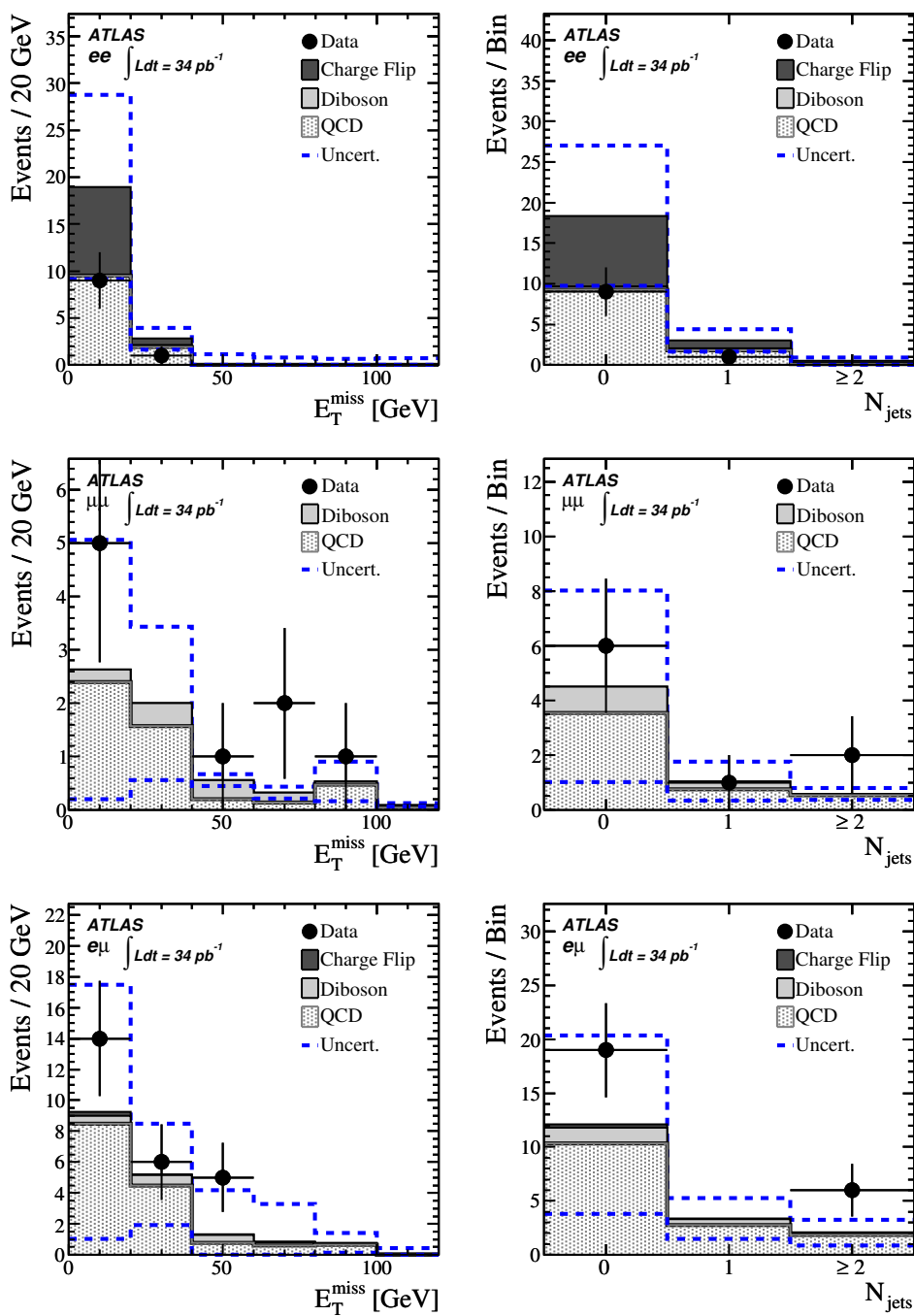


Figure 5. Distributions of missing transverse momentum (left) and jet multiplicity (right) in same-sign ee (top), $\mu\mu$ (center) and $e\mu$ (bottom) channels. Shown are data (points) and backgrounds (solid stacked histograms). The combined statistical and systematic uncertainty is shown as a dashed blue line. Overflow events are included in the final bin. In the ee channel, the Z reflection is suppressed by excluding $80 < m_{\ell\ell} < 95$ GeV.

	n_{obs}	n_{pred}	σ_{obs}^{95} [pb]	σ_{exp}^{95} [pb]
ee	0	$3.1 \pm 2.1 \pm 0.5$	0.15	0.46
$\mu\mu$	1	$2.2 \pm 1.4 \pm 0.4$	0.17	0.25
$e\mu$	3	$3.2 \pm 2.9 \pm 0.5$	0.28	0.28

Table 4. The observed (n_{obs}) and predicted (n_{pred}) yields of same-sign dilepton events with large dilepton invariant mass $m_{\ell\ell} > 110$ GeV. Uncertainties are statistical followed by systematic. Upper limits at 95% CL are placed on the fiducial cross-section (σ_{obs}^{95}) of a new high-mass source in each channel. Also given is the median expected limit (σ_{exp}^{95}) in simulated experiments drawn from the background hypothesis.

In the high-mass domain specified above ($m_{\ell\ell} > 110$ GeV), limits are set by the prescription of Feldman and Cousins [50]. In this method, confidence intervals are built from a likelihood-ratio test statistic. Ensembles of simulated experiments are generated that capture fluctuations expected from the statistical and systematic uncertainties. The observed upper limit on the cross-section of a new high-mass source is given for each channel in table 4. In the ee and $\mu\mu$ channels, the observed limits are somewhat lower than the expected limits because the number of events observed in these channels is lower than the number predicted by the Standard Model.

Efficiencies to pass the baseline selection in a fiducial region defined by dilepton invariant mass $m_{\ell\ell} > 110$ GeV, lepton transverse momentum $p_T > 20$ GeV, lepton pseudorapidity $|\eta| < 2.5$, and $\Delta R(\text{lepton, quark or gluon}) > 0.4$ (considering only quarks or gluons with $p_T > 15$ GeV from the hard scattering process after initial- and final-state radiation but before hadronization) are given in table 5 for several models, described in the next section. These sample efficiencies demonstrate the degree of model independence of the fiducial cross-section limits shown in table 4.

In setting fiducial cross-section limits, the smallest efficiency for events within the fiducial acceptance found for each channel is used. These limits are rather general, and should be applicable to any model producing a significant fraction of isolated high-mass lepton pairs.

8 Limits on specific models

The data are interpreted to set limits on four models with same-sign dilepton signals from new physics sources. For each model, upper limits at 95% CL on the cross-sections of the hypothetical processes are derived using the Feldman-Cousins (FC) method for choosing the 95% region of the frequentist Neyman construction. In setting limits, the predicted signal plus background histograms in the chosen variable are used as templates and fit to the data to extract the most likely signal cross-section, which is used in turn to calculate upper limits with the FC procedure. Systematic uncertainties are included as variations in the signal and background templates, which are fluctuated in the ensembles used to generate the Neyman construction. The cross-section limits are presented as functions of the masses of the hypothetical new particles that the particular models introduce.

Signal model	Reconstruction efficiency		
	ee	$e\mu$	$\mu\mu$
Majorana neutrino with $m_N = 200$ GeV	$(46\pm 1)\%$	$(58\pm 1)\%$	$(71\pm 2)\%$
Fourth-generation d_4 with $m_{d_4} = 350$ GeV	$(46\pm 2)\%$	$(53\pm 2)\%$	$(67\pm 2)\%$
Lepton cascade topology with $m_{\tilde{q}} = 500$ GeV, $m_{\tilde{\chi}_1^\pm, \tilde{\chi}_2^0} = 450$ GeV, $m_{\text{LSP}} = 100$ GeV	$(46\pm 1)\%$	$(53\pm 1)\%$	$(67\pm 2)\%$
Left-right symmetry with $m_{W_R} = 600$ GeV, $m_N = 50$ GeV	$(40\pm 2)\%$	—	$(62\pm 2)\%$

Table 5. Reconstruction efficiency of same-sign dilepton events generated in various models in a fiducial region defined by dilepton invariant mass $m_{\ell\ell} > 110$ GeV, lepton transverse momentum $p_T > 20$ GeV, lepton pseudorapidity $|\eta| < 2.5$ and $\Delta R(\text{lepton, quark or gluon}) > 0.4$. Statistical uncertainties are given. A dash indicates that the channel is not a final state of a particular model.

8.1 Majorana neutrinos

Production of heavy Majorana neutrinos described by effective operators [12] and LRS theories [15] have dilepton signatures that also include jets. To set limits on these models, the subsample of events with at least one jet is considered. The $m_{\ell\ell}$ distributions for the ee , $e\mu$ and $\mu\mu$ channels are shown in the top row of figure 6 after also requiring $N_{jets} > 0$. Hypothetical signal predictions are overlaid.

For models of Majorana neutrinos, a single resonance drives the lepton kinematics. This leaves the $m_{\ell\ell}$ spectrum most sensitive to these models, and so it is used to form the templates with which we derive upper limits. The KS-distance of this distribution is 0.19, with a SM p -value of 88% for the three channels combined.

In the first model considered, Majorana neutrinos are produced by a four-fermion vector operator V [12]. The effective Lagrangian formalism of this model requires a choice for the energy scale Λ of new phenomena. It is taken to have magnitude 1 TeV. The coupling of V is chosen to be one, the natural scale of the model. All other effective operator couplings are assumed to vanish. The effective vector operator was simulated by the CALCHEP 2.4.5 simulation program [51].

The observed cross-section limit for this description is interpreted in terms of neutrino mass, shown in figure 7 (left). Majorana neutrino mass values are excluded below 460 GeV. The observed limits are consistent with limits expected when no Majorana neutrino is present.

Majorana neutrino production by the LRS model [15] is also considered. In this model, the right-handed W_R boson decays to a lepton and a Majorana neutrino that in turn decays to a same-sign lepton and one or more jets. The simulated signal for this model was

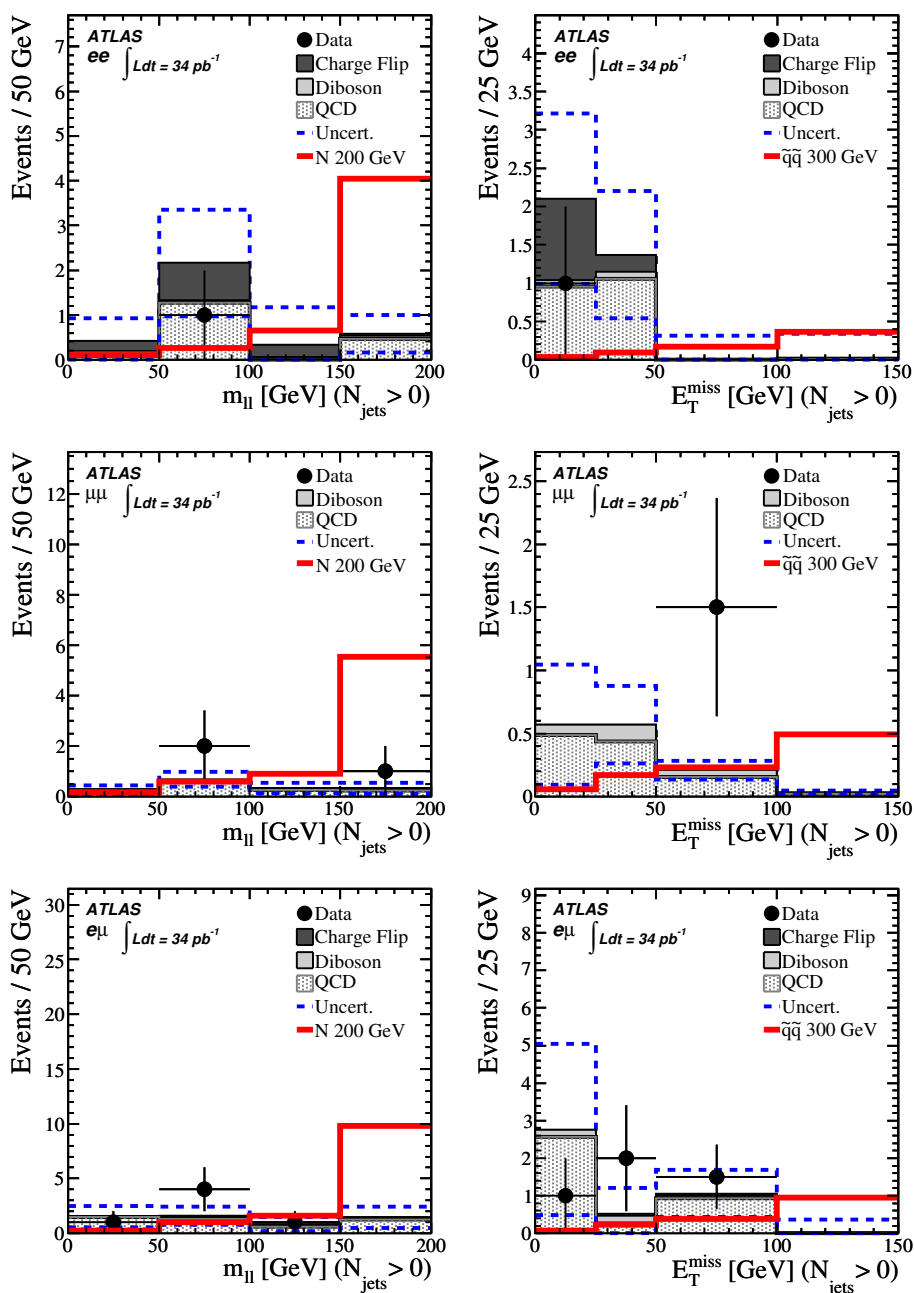


Figure 6. Distributions of dilepton invariant mass (left) and missing transverse momentum (right) with at least one jet in ee (top), $\mu\mu$ (center) and $e\mu$ (bottom) channels. Shown are data (points) and backgrounds (solid stacked histograms). The combined statistical and systematic uncertainty is shown as a dashed blue line. Overflow events are included in the final bin. In the ee channel, the Z reflection has been suppressed by excluding $80 < m_{\ell\ell} < 95$ GeV. For the dilepton invariant mass distribution, expected contribution from Majorana neutrinos with $m_N = 200$ GeV is shown; for missing transverse momentum, expected contribution is shown from lepton cascades with $m_{\tilde{q}} = 300$ GeV, $m_{\tilde{\chi}_1^+} = 150$ GeV, $m_{\tilde{\chi}_1^0} = 50$ GeV.

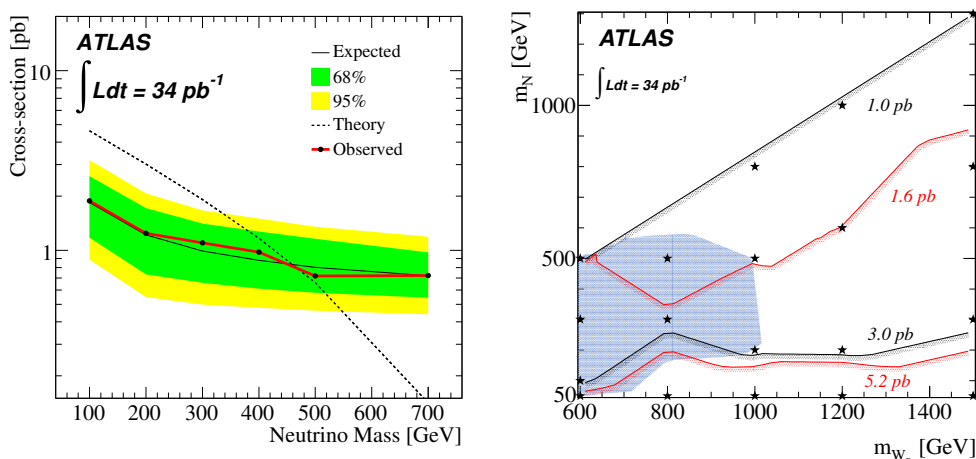


Figure 7. Limits at 95% CL on two different production models of Majorana neutrinos. Left: for a model of Majorana neutrinos which uses an effective vector operator, observed and expected cross-section limits [pb] as a function of Majorana neutrino mass produced, assuming a natural coupling and an energy scale of new phenomena $\Lambda = 1$ TeV. Right: for the LRS model, contours of observed cross-section upper limits [pb] as a function of Majorana neutrino and W_R masses in LRS theories are shown. The space is sampled in a rough grid (sample points indicated by a \star) and the limits are interpolated. The exclusion region is shaded.

generated using PYTHIA with MRST2008LO* modified leading-order PDFs. The leading-order theoretical cross-section was used.

The observed limits are shown in figure 7 (right) as a function of the masses of the Majorana neutrino (m_N) and the right-handed W_R boson (m_{W_R}). The shaded exclusion region represents mass points for which the observed cross-section limit is lower than the theoretical cross-section. Contours of constant cross-section limit are overlaid. Observed limits are consistent with expected limits everywhere.

The theoretical cross-section and decay kinematics are determined by the mass difference between the neutrino and a right-handed boson, W_R . A large mass difference yields highly relativistic heavy neutrinos, with one lepton typically overlapped by a jet in the event and thus failing the isolation criteria. Nevertheless, we exclude W_R with masses less than 0.7 TeV over most of the parameter space, as well as masses less than 1.0 TeV for a large range of neutrino masses.

8.2 Lepton cascades

A specific cascade topology (shown in figure 8) is considered that produces a same-sign dilepton signature and invisible particles [17]. Since the final states would include jets, the subsample of events with at least one jet is again considered. In lepton cascades leading to invisible particles common to supersymmetric and UED models, a heavy neutral particle escapes detection, and so E_T^{miss} is used to form the templates with which we derive upper limits. The E_T^{miss} distributions for the ee , $e\mu$ and $\mu\mu$ channels are shown in the bottom row

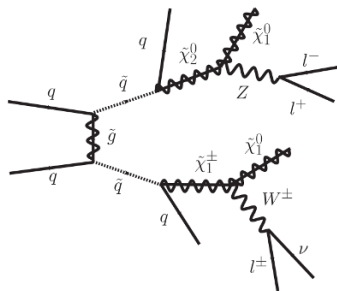


Figure 8. Feynman diagram of cascade topology denoted in supersymmetric nomenclature. The analysis is done with WW , ZZ and WZ combinations of weak vector bosons; WZ is shown in the diagram. This topology may also be found in other models such as UED.

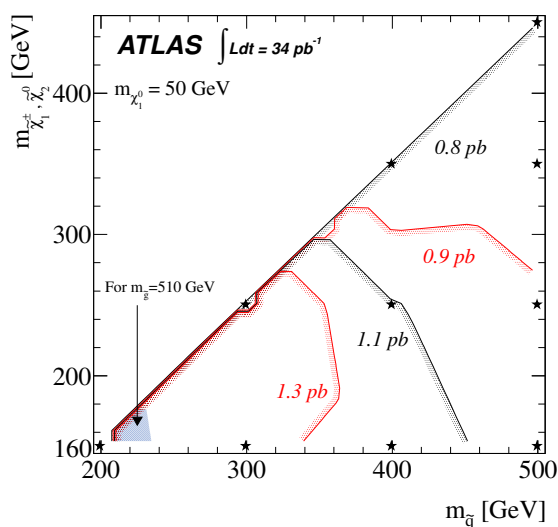


Figure 9. Observed 95% CL upper cross-section limits [pb] as a function of $m_{\tilde{\chi}_1^\pm, \tilde{\chi}_2^0}$ and $m_{\tilde{q}}$ for $m_{\tilde{\chi}_1^0} = 50$ GeV. As an example, we exclude a portion of parameter space (shaded) assuming a gluino mass of 510 GeV in order to calculate the cross-section. (This mass value is chosen to be greater than 500 GeV, the largest squark mass considered, but is otherwise arbitrary.) The mix of processes (equations (8.1)–(8.3)) included in the signal model is given in section 8.2. The space is sampled in a rough grid (sample points indicated by a \star) and the limits are interpolated.

of figure 6 after also requiring $N_{jets} > 0$. Hypothetical signal predictions are overlaid. The KS-distance of this distribution is 0.29, with a SM p -value of 67% for the three channels combined.

Although particle names are denoted here in a supersymmetry context, these cascade topologies occur quite generally, such as in models with universal extra dimensions [46, 47]. The topology is described using the minimal particle content necessary, and the effective theory is parameterised directly in the masses of the new particles, making the conclusions independent of any fundamental parameters specific to a particular theory.

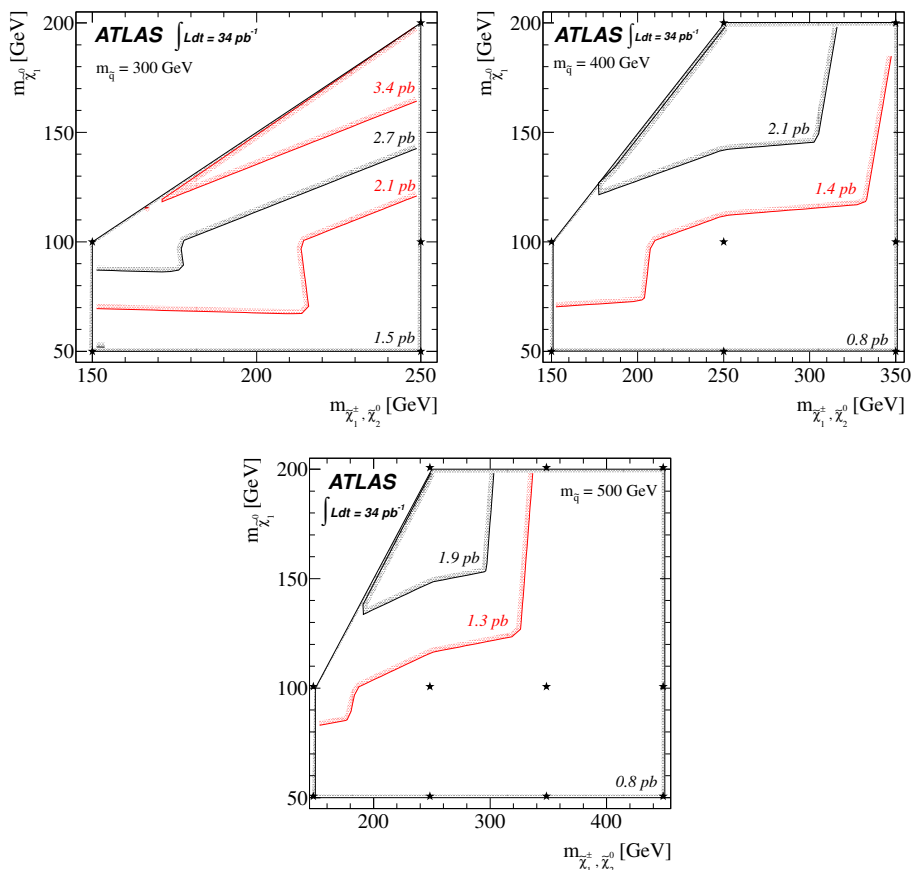


Figure 10. From left: observed 95% CL cross-section upper limits [pb] as a function of $m_{\tilde{\chi}_1^\pm, \tilde{\chi}_2^0}$ and $m_{\tilde{\chi}_1^\pm}$ for $m_{\tilde{q}} = 300, 400,$ and 500 GeV. The mix of processes (equations (8.1)–(8.3)) included in the signal model is given in section 8.2. The space is sampled in a rough grid (sample points indicated by a \star) and the limits are interpolated.

In this scheme there are three processes:

$$\tilde{q}\tilde{q} \rightarrow \tilde{\chi}_1^\pm \tilde{\chi}_1^\pm qq \rightarrow W^\pm W^\pm \tilde{\chi}_1^0 \tilde{\chi}_1^0 qq \quad (8.1)$$

$$\tilde{q}\tilde{q} \rightarrow \tilde{\chi}_1^\pm \tilde{\chi}_2^0 qq \rightarrow W^\pm Z \tilde{\chi}_1^0 \tilde{\chi}_1^0 qq \quad (8.2)$$

$$\tilde{q}\tilde{q} \rightarrow \tilde{\chi}_2^0 \tilde{\chi}_2^0 qq \rightarrow ZZ \tilde{\chi}_1^0 \tilde{\chi}_1^0 qq \quad (8.3)$$

Leptonic decay modes of the W and Z bosons are considered. This analysis uses an admixture that equally favours combinations of the chargino $\tilde{\chi}_1^\pm$ and neutralino $\tilde{\chi}_2^0$ (assumed to have the same mass), $\text{BF}(\tilde{q} \rightarrow q\tilde{\chi}_1^\pm) = \text{BF}(\tilde{q} \rightarrow q\tilde{\chi}_2^0) = 0.5$, resulting in a 1:2:1 composition of the three processes above. If all decay modes are considered, the number of events expected from the WW process is higher than from the other channels due to the higher leptonic branching fractions of W bosons. Considering only leptonic decays, the two pairs of same-sign leptons in ZZ events lead to twice the selection efficiency of the other two channels. The limits presented can be scaled to constrain other mixtures of W and Z decays.

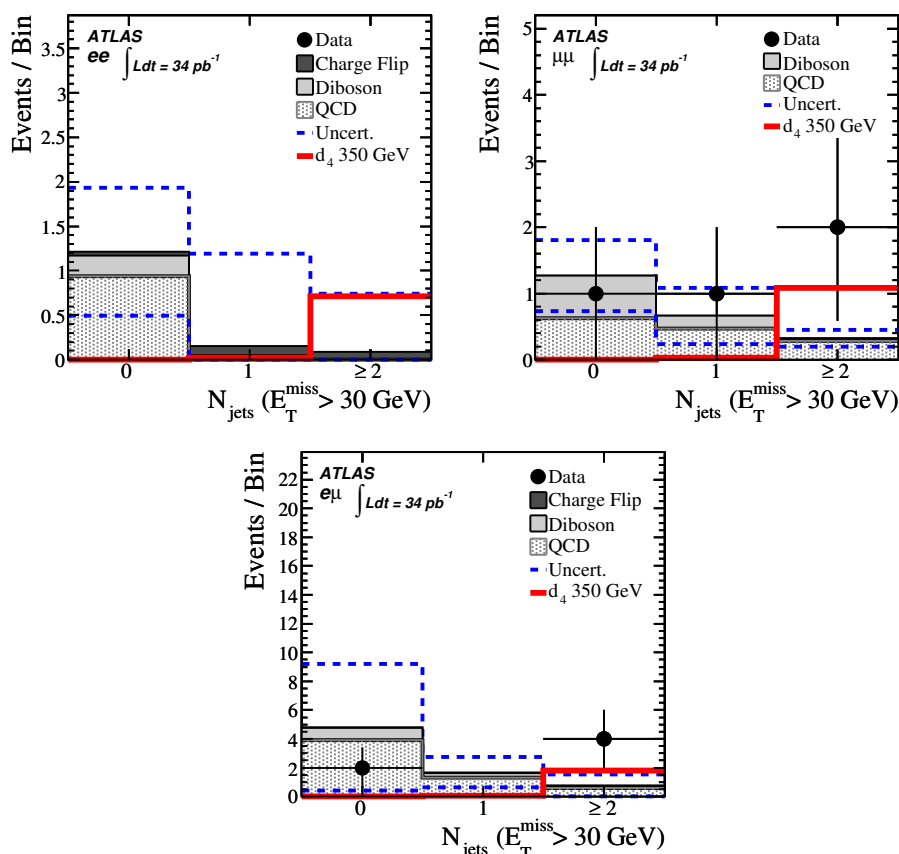


Figure 11. Distributions of jet multiplicity with $E_T^{\text{miss}} > 30$ GeV in ee (top left), $\mu\mu$ (top right) and $e\mu$ (bottom) channels. The final bin includes events with two or more jets. Shown are data (points) and backgrounds (solid stacked histograms). The combined statistical and systematic uncertainty is shown as a dashed blue line. Overflow events are included in the final bin. In the ee channel, the Z reflection is suppressed by excluding $80 < m_{\ell\ell} < 95$ GeV.

Cross-section limits (figure 9 and figure 10) are presented as a function of the masses of a chargino/neutralino, the squark (\tilde{q}), and the lightest supersymmetric particle ($\tilde{\chi}_1^0$), which is neutral and stable. The observed limits are consistent with expected limits in the no-signal hypothesis. These cross-section limits apply to any theory with a non-zero cross section from this topology (scaled by the appropriate branching fraction). They depend on the experimental acceptance, and the particle masses, with no significant dependence on other characteristics such as particle spin. To set mass limits on a particular model, one would need only to find the intersection of the predicted cross-section with the observed cross-section upper limits. For example, one may consider a supersymmetric theory with a gluino mass of 510 GeV. The exclusion region for this model is shown in figure 9. The signal expected from this topology was generated using MADGRAPH for the hard-scattering and initial squark production, and BRIDGE [48] for particle decay.

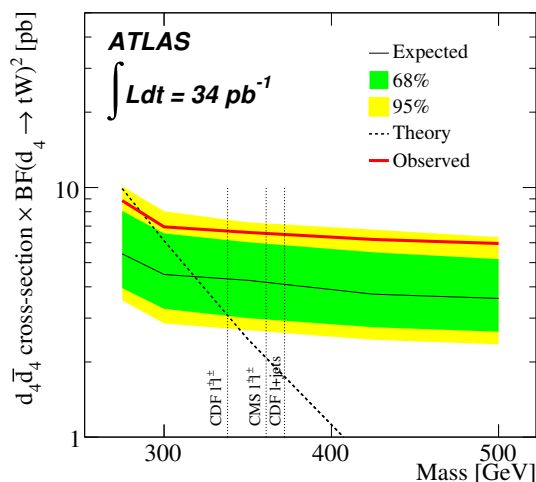


Figure 12. Expected and observed 95% CL limits on d_4 production cross-section as a function of its mass, compared to limits from CDF [6, 16] and CMS [5].

8.3 Heavy down-type quarks

The last model considered has a fourth-generation d -type quark decaying to tW [18], and is tested using the jet multiplicity distribution in events with significant missing transverse momentum, $E_T^{\text{miss}} > 30$ GeV. The jet multiplicity of events in this subsample is shown in figure 11. The KS-distance of this distribution is 0.45, with a SM p -value of 31%, for the three channels combined.

The signal from $d_4\bar{d}_4$ production includes significant missing momentum carried by neutrinos. The signal expected in this model was generated using PYTHIA. Events with $E_T^{\text{miss}} > 30$ GeV are selected from the inclusive sample to set limits on this model. The limits are derived using a three-bin template: zero, one and two or more jets, due to the small number of events used to estimate the flavour fake contribution at high jet multiplicities.

The observed and Standard Model expected cross-section limits for d_4 production assuming $\text{BF}(d_4 \rightarrow tW) = 1$ are shown in figure 12. The intersection of the limit with the next-to-next-to-leading order theoretical cross-section yields a lower bound of 290 GeV on the d_4 mass, which is somewhat lower than the expected limit of 320 GeV due to high-multiplicity events observed in the $e\mu$ and $\mu\mu$ channels. Such weaker limits are observed in 10% of simulated experiments drawn from the background hypothesis.

9 Conclusion

The yields in ee , $e\mu$, and $\mu\mu$ are measured and the observed high- p_T isolated same-sign dilepton events show no significant discrepancy with the SM. In a model-independent statistical analysis of the inclusive sample, no evidence of unknown physical sources of same-sign dilepton events is found. Considering the dilepton invariant mass spectrum integrated

above 110 GeV, we set upper limits on the fiducial cross-section of a new high-mass source, $0.13(ee), 0.17(\mu\mu), 0.32(e\mu)$ pb (95% CL).

Experimental sensitivity is demonstrated to four specific models of new phenomena that could be discovered in pp collisions at the LHC. Constraints are interpreted in the analysis of subsamples with non-zero jet multiplicity or $E_T^{\text{miss}} > 30$ GeV. Majorana neutrino mass values below 460 GeV are excluded for production by the effective operator V assuming a new physics scale of 1 TeV. Also excluded are LRS W_R with mass less than 0.7 TeV over most of the parameter space, and mass less than 1.0 TeV for a large range of neutrino masses. Cross-section limits are provided on a generic topology of supersymmetry and UED, as a function of the masses of field quanta. These limits may be applied to any model with contributions from this topology by appropriate scaling. Finally, a lower limit of 290 GeV is obtained on the mass of fourth generation d -type quarks.

Acknowledgments

We wish to thank CERN for the efficient commissioning and operation of the LHC during this initial high-energy data-taking period as well as the support staff from our institutions without whom ATLAS could not be operated efficiently.

We acknowledge the support of ANPCyT, Argentina; YerPhI, Armenia; ARC, Australia; BMWF, Austria; ANAS, Azerbaijan; SSTC, Belarus; CNPq and FAPESP, Brazil; NSERC, NRC and CFI, Canada; CERN; CONICYT, Chile; CAS, MOST and NSFC, China; COLCIENCIAS, Colombia; MSMT CR, MPO CR and VSC CR, Czech Republic; DNRF, DNSRC and Lundbeck Foundation, Denmark; ARTEMIS, European Union; IN2P3-CNRS, CEA-DSM/IRFU, France; GNAS, Georgia; BMBF, DFG, HGF, MPG and AvH Foundation, Germany; GSRT, Greece; ISF, MINERVA, GIF, DIP and Benoziyo Center, Israel; INFN, Italy; MEXT and JSPS, Japan; CNRST, Morocco; FOM and NWO, Netherlands; RCN, Norway; MNiSW, Poland; GRICES and FCT, Portugal; MERYS (MECTS), Romania; MES of Russia and ROSATOM, Russian Federation; JINR; MSTP, Serbia; MSSR, Slovakia; ARRS and MVZT, Slovenia; DST/NRF, South Africa; MICINN, Spain; SRC and Wallenberg Foundation, Sweden; SER, SNSF and Cantons of Bern and Geneva, Switzerland; NSC, Taiwan; TAEK, Turkey; STFC, the Royal Society and Leverhulme Trust, United Kingdom; DOE and NSF, United States of America.

The crucial computing support from all WLCG partners is acknowledged gratefully, in particular from CERN and the ATLAS Tier-1 facilities at TRIUMF (Canada), NDGF (Denmark, Norway, Sweden), CC-IN2P3 (France), KIT/GridKA (Germany), INFN-CNAF (Italy), NL-T1 (Netherlands), PIC (Spain), ASGC (Taiwan), RAL (UK) and BNL (USA) and in the Tier-2 facilities worldwide.

Open Access. This article is distributed under the terms of the Creative Commons Attribution Noncommercial License which permits any noncommercial use, distribution, and reproduction in any medium, provided the original author(s) and source are credited.

References

- [1] ATLAS collaboration, G. Aad et al., *Search for supersymmetric particles in events with lepton pairs and large missing transverse momentum in $\sqrt{s} = 7$ TeV proton-proton collisions with the ATLAS experiment*, *Eur. Phys. J. C* **71** (2011) 1682 [[arXiv:1103.6214](#)] [[SPIRES](#)].
- [2] CMS collaboration, S. Chatrchyan et al., *Search for new physics with same-sign isolated dilepton events with jets and missing transverse energy at the LHC*, *JHEP* **06** (2011) 077 [[arXiv:1104.3168](#)] [[SPIRES](#)].
- [3] CDF collaboration, A. Abulencia et al., *Inclusive search for new physics with like-sign dilepton events in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV*, *Phys. Rev. Lett.* **98** (2007) 221803 [[hep-ex/0702051](#)] [[SPIRES](#)].
- [4] CDF collaboration, D. Acosta et al., *Inclusive search for anomalous production of high- p_T like-sign lepton pairs in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV*, *Phys. Rev. Lett.* **93** (2004) 061802 [[hep-ex/0405063](#)] [[SPIRES](#)].
- [5] CMS collaboration, S. Chatrchyan et al., *Search for a Heavy Bottom-like Quark in pp Collisions at $\sqrt{s} = 7$ TeV*, *Phys. Lett. B* **701** (2011) 204 [[arXiv:1102.4746](#)] [[SPIRES](#)].
- [6] CDF collaboration, T. Aaltonen et al., *Search for New Bottomlike Quark Pair Decays $Q\bar{Q} \rightarrow (tW^\mp)(\bar{t}W^\pm)$ in Same-Charge Dilepton Events*, *Phys. Rev. Lett.* **104** (2010) 091801 [[arXiv:0912.1057](#)] [[SPIRES](#)].
- [7] D0 collaboration, V.M. Abazov et al., *Search for W -prime Boson Resonances Decaying to a Top Quark and a Bottom Quark*, *Phys. Rev. Lett.* **100** (2008) 211803 [[arXiv:0803.3256](#)] [[SPIRES](#)].
- [8] CDF collaboration, T. Aaltonen et al., *Search for Maximal Flavor Violating Scalars in Same-Charge Lepton Pairs in $p\bar{p}$ Collisions at $\sqrt{s} = 1.96$ TeV*, *Phys. Rev. Lett.* **102** (2009) 041801 [[arXiv:0809.4903](#)] [[SPIRES](#)].
- [9] CDF collaboration, T. Affolder et al., *Search for gluinos and squarks using like sign dileptons in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV*, *Phys. Rev. Lett.* **87** (2001) 251803 [[hep-ex/0106061](#)] [[SPIRES](#)].
- [10] CDF collaboration, F. Abe et al., *Search for R -parity violating supersymmetry using like sign dielectrons in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV*, *Phys. Rev. Lett.* **83** (1999) 2133 [[hep-ex/9908063](#)] [[SPIRES](#)].
- [11] D0 collaboration, V.M. Abazov et al., *Search for associated Higgs boson production $WH \rightarrow WWW^* \rightarrow l^\pm \nu l'^\pm \nu' + X$ in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV*, *Phys. Rev. Lett.* **97** (2006) 151804 [[hep-ex/0607032](#)] [[SPIRES](#)].
- [12] F. del Aguila, S. Bar-Shalom, A. Soni and J. Wudka, *Heavy Majorana Neutrinos in the Effective Lagrangian Description: Application to Hadron Colliders*, *Phys. Lett. B* **670** (2009) 399 [[arXiv:0806.0876](#)] [[SPIRES](#)].
- [13] W.-Y. Keung and G. Senjanović, *Majorana neutrinos and the production of the right-handed charged gauge boson*, *Phys. Rev. Lett.* **50** (1983) 1427 [[SPIRES](#)].
- [14] D0 collaboration, S. Abachi et al., *Search for right-handed W bosons and heavy w -prime in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV*, *Phys. Rev. Lett.* **76** (1996) 3271 [[hep-ex/9512007](#)] [[SPIRES](#)].
- [15] R.N. Mohapatra and J.C. Pati, *A Natural Left-Right Symmetry*, *Phys. Rev. D* **11** (1975) 2558 [[SPIRES](#)].

- [16] THE CDF collaboration, T. Aaltonen et al., *Search for heavy bottom-like quarks decaying to an electron or muon and jets in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV*, *Phys. Rev. Lett.* **106** (2011) 141803 [[arXiv:1101.5728](#)] [[SPIRES](#)].
- [17] J. Alwall, P. Schuster and N. Toro, *Simplified Models for a First Characterization of New Physics at the LHC*, *Phys. Rev.* **D 79** (2009) 075020 [[arXiv:0810.3921](#)] [[SPIRES](#)].
- [18] P.H. Frampton, P.Q. Hung and M. Sher, *Quarks and leptons beyond the third generation*, *Phys. Rept.* **330** (2000) 263 [[hep-ph/9903387](#)] [[SPIRES](#)].
- [19] ATLAS collaboration, G. Aad et al., *The ATLAS Experiment at the CERN Large Hadron Collider*, *2008 JINST* **3** S08003 [[SPIRES](#)].
- [20] ATLAS collaboration, G. Aad et al., *Measurement of the $W^- \rightarrow l\nu$ and $Z/\gamma^* \rightarrow ll$ production cross sections in proton-proton collisions at $\sqrt{s} = 7$ TeV with the ATLAS detector*, *JHEP* **12** (2010) 060 [[arXiv:1010.2130](#)] [[SPIRES](#)].
- [21] ATLAS collaboration, G. Aad et al., *The ATLAS Simulation Infrastructure*, *Eur. Phys. J.* **C 70** (2010) 823 [[arXiv:1005.4568](#)] [[SPIRES](#)].
- [22] GEANT4 collaboration, S. Agostinelli et al., *GEANT4: A simulation toolkit*, *Nucl. Instrum. Meth.* **A 506** (2003) 250 [[SPIRES](#)].
- [23] ATLAS collaboration, *ATLAS Monte Carlo tunes for MC09*, ATL-PHYS-PUB-2010-002 (2010).
- [24] M.L. Mangano, M. Moretti, F. Piccinini, R. Pittau and A.D. Polosa, *ALPGEN, a generator for hard multiparton processes in hadronic collisions*, *JHEP* **07** (2003) 001 [[hep-ph/0206293](#)] [[SPIRES](#)].
- [25] J. Pumplin et al., *New Generation of Parton Distributions with Uncertainties from Global QCD Analysis*, *JHEP* **07** (2002) 012.
- [26] G. Marchesini et al., *HERWIG: A Monte Carlo event generator for simulating hadron emission reactions with interfering gluons. Version 5.1 - April 1991*, *Comput. Phys. Commun.* **67** (1992) 465 [[SPIRES](#)].
- [27] G. Corcella et al., *HERWIG 6.5: an event generator for Hadron Emission Reactions With Interfering Gluons (including supersymmetric processes)*, *JHEP* **01** (2001) 010 [[hep-ph/0011363](#)] [[SPIRES](#)].
- [28] G. Corcella et al., *HERWIG 6.5 release note*, [hep-ph/0210213](#) [[SPIRES](#)].
- [29] A. Sherstnev and R.S. Thorne, *Parton Distributions for LO Generators*, *Eur. Phys. J.* **C 55** (2008) 553 [[arXiv:0711.2473](#)] [[SPIRES](#)].
- [30] J. Alwall et al., *MadGraph/MadEvent v4: The New Web Generation*, *JHEP* **09** (2007) 028 [[arXiv:0706.2334](#)] [[SPIRES](#)].
- [31] T. Sjöstrand, S. Mrenna and P.Z. Skands, *PYTHIA 6.4 Physics and Manual*, *JHEP* **05** (2006) 026 [[hep-ph/0603175](#)] [[SPIRES](#)].
- [32] S. Frixione and B.R. Webber, *Matching NLO QCD computations and parton shower simulations*, *JHEP* **06** (2002) 029 [[hep-ph/0204244](#)] [[SPIRES](#)].
- [33] S. Frixione, P. Nason and B.R. Webber, *Matching NLO QCD and parton showers in heavy flavour production*, *JHEP* **08** (2003) 007 [[hep-ph/0305252](#)] [[SPIRES](#)].
- [34] M. Aliev et al., *HATHOR: HAdronic Top and Heavy quarks crOss section calculatoR*, *Comput. Phys. Commun.* **182** (2011) 1034 [[arXiv:1007.1327](#)] [[SPIRES](#)].

- [35] S. Hassani et al., *A muon identification and combined reconstruction procedure for the ATLAS detector at the LHC using the (MUONBOY, STACO, MuTag) reconstruction packages*, *Nucl. Instrum. Meth. A* **572** (2007) 77 [SPIRES].
- [36] M. Cacciari, G.P. Salam and G. Soyez, *The anti- k_t jet clustering algorithm*, *JHEP* **04** (2008) 063 [arXiv:0802.1189] [SPIRES].
- [37] M. Cacciari and G.P. Salam, *Dispelling the N^3 myth for the k_t jet-finder*, *Phys. Lett. B* **641** (2006) 57 [hep-ph/0512210] [SPIRES].
- [38] ATLAS collaboration, *Jet energy scale and its systematic uncertainty in proton-proton collisions at $\sqrt{s} = 7$ TeV with ATLAS 2010 data*, ATLAS-CONF-2011-032 (2011).
- [39] ATLAS collaboration, G. Aad et al., *Measurement of the top quark-pair production cross section with ATLAS in pp collisions at $\sqrt{s} = 7$ TeV*, *Eur. Phys. J. C* **71** (2011) 1577 [arXiv:1012.1792] [SPIRES].
- [40] ATLAS collaboration, G. Aad et al., *Search for Diphoton Events with Large Missing Transverse Energy in 7 TeV Proton-Proton Collisions with the ATLAS Detector*, *Phys. Rev. Lett.* **106** (2011) 121803 [arXiv:1012.4272] [SPIRES].
- [41] J. Zhong, R.-S. Huang and S.-C. Lee, *A program for the Bayesian Neural Network in the ROOT framework*, *Comput. Phys. Commun.* **182** (2011) 2655 [arXiv:1103.2854] [SPIRES].
- [42] A. Hocker et al., *TMVA - Toolkit for Multivariate Data Analysis*, **PoS(ACAT08)040**.
- [43] D.J.C. MacKay, *Probable networks and plausible predictions — a review of practical Bayesian methods for supervised neural networks*, *Net. Comp. Neu. Sys.* **6** (1995) 469.
- [44] ATLAS collaboration, *Updated Luminosity Determination in pp Collisions at $\sqrt{s} = 7$ TeV using the ATLAS Detector*, ATLAS-CONF-2011-011 (2011).
- [45] ATLAS collaboration, G. Aad et al., *Luminosity Determination in pp Collisions at $\sqrt{s} = 7$ TeV Using the ATLAS Detector at the LHC*, *Eur. Phys. J. C* **71** (2011) 1630 [arXiv:1101.2185] [SPIRES].
- [46] T. Appelquist, H.-C. Cheng and B.A. Dobrescu, *Bounds on universal extra dimensions*, *Phys. Rev. D* **64** (2001) 035002 [hep-ph/0012100] [SPIRES].
- [47] T.G. Rizzo, *Probes of universal extra dimensions at colliders*, *Phys. Rev. D* **64** (2001) 095010 [hep-ph/0106336] [SPIRES].
- [48] P. Meade and M. Reece, *BRIDGE: Branching ratio inquiry/decay generated events*, **hep-ph/0703031** [SPIRES].
- [49] F.J. Massey Jr., *The Kolmogorov-Smirnov Test for Goodness of Fit*, *J. Am. Stat. Ass.* **46** (1951) 68.
- [50] G.J. Feldman and R.D. Cousins, *A Unified Approach to the Classical Statistical Analysis of Small Signals*, *Phys. Rev. D* **57** (1998) 3873 [physics/9711021].
- [51] A. Pukhov, *CalcHEP 2.3: MSSM, structure functions, event generation, batchs and generation of matrix elements for other packages*, **hep-ph/0412191** [SPIRES].

The ATLAS collaboration

G. Aad⁴⁸, B. Abbott¹¹¹, J. Abdallah¹¹, A.A. Abdelalim⁴⁹, A. Abdesselam¹¹⁸, O. Abdinov¹⁰, B. Abi¹¹², M. Abolins⁸⁸, H. Abramowicz¹⁵³, H. Abreu¹¹⁵, E. Acerbi^{89a,89b}, B.S. Acharya^{164a,164b}, D.L. Adams²⁴, T.N. Addy⁵⁶, J. Adelman¹⁷⁵, M. Aderholz⁹⁹, S. Adomeit⁹⁸, P. Adragna⁷⁵, T. Adye¹²⁹, S. Aefsky²², J.A. Aguilar-Saavedra^{124b,a}, M. Aharrouche⁸¹, S.P. Ahlen²¹, F. Ahles⁴⁸, A. Ahmad¹⁴⁸, M. Ahsan⁴⁰, G. Aielli^{133a,133b}, T. Akdogan^{18a}, T.P.A. Åkesson⁷⁹, G. Akimoto¹⁵⁵, A.V. Akimov⁹⁴, A. Akiyama⁶⁷, M.S. Alam¹, M.A. Alam⁷⁶, S. Albrand⁵⁵, M. Aleksa²⁹, I.N. Aleksandrov⁶⁵, F. Alessandria^{89a}, C. Alexa^{25a}, G. Alexander¹⁵³, G. Alexandre⁴⁹, T. Alexopoulos⁹, M. Alhroob²⁰, M. Aliev¹⁵, G. Alimonti^{89a}, J. Alison¹²⁰, M. Aliyev¹⁰, P.P. Allport⁷³, S.E. Allwood-Spiers⁵³, J. Almond⁸², A. Aloisio^{102a,102b}, R. Alon¹⁷¹, A. Alonso⁷⁹, M.G. Alvigi^{102a,102b}, K. Amako⁶⁶, P. Amaral²⁹, C. Amelung²², V.V. Ammosov¹²⁸, A. Amorim^{124a,b}, G. Amorós¹⁶⁷, N. Amram¹⁵³, C. Anastopoulos¹³⁹, T. Andeen³⁴, C.F. Anders²⁰, K.J. Anderson³⁰, A. Andreazza^{89a,89b}, V. Andrei^{58a}, M-L. Andrieux⁵⁵, X.S. Anduaga⁷⁰, A. Angerami³⁴, F. Anghinolfi²⁹, N. Anjos^{124a}, A. Annovi⁴⁷, A. Antonaki⁸, M. Antonelli⁴⁷, S. Antonelli^{19a,19b}, A. Antonov⁹⁶, J. Antos^{144b}, F. Anulli^{132a}, S. Aoun⁸³, L. Aperio Bella⁴, R. Apolle^{118,c}, G. Arabidze⁸⁸, I. Aracena¹⁴³, Y. Arai⁶⁶, A.T.H. Arce⁴⁴, J.P. Archambault²⁸, S. Arfaoui^{29,d}, J-F. Arguin¹⁴, E. Arik^{18a,*}, M. Arik^{18a}, A.J. Armbruster⁸⁷, O. Arnaez⁸¹, C. Arnault¹¹⁵, A. Artamonov⁹⁵, G. Artoni^{132a,132b}, D. Arutinov²⁰, S. Asai¹⁵⁵, R. Asfandiyarov¹⁷², S. Ask²⁷, B. Åsman^{146a,146b}, L. Asquith⁵, K. Assamagan²⁴, A. Astbury¹⁶⁹, A. Astvatsatourov⁵², G. Atoian¹⁷⁵, B. Aubert⁴, B. Auerbach¹⁷⁵, E. Auge¹¹⁵, K. Augsten¹²⁷, M. Auresseau^{145a}, N. Austin⁷³, R. Avramidou⁹, D. Axen¹⁶⁸, C. Ay⁵⁴, G. Azuelos^{93,e}, Y. Azuma¹⁵⁵, M.A. Baak²⁹, G. Baccaglioni^{89a}, C. Bacci^{134a,134b}, A.M. Bach¹⁴, H. Bachacou¹³⁶, K. Bachas²⁹, G. Bachy²⁹, M. Backes⁴⁹, M. Backhaus²⁰, E. Badescu^{25a}, P. Bagnaia^{132a,132b}, S. Bahinipati², Y. Bai^{32a}, D.C. Bailey¹⁵⁸, T. Bain¹⁵⁸, J.T. Baines¹²⁹, O.K. Baker¹⁷⁵, M.D. Baker²⁴, S. Baker⁷⁷, F. Baltasar Dos Santos Pedrosa²⁹, E. Banas³⁸, P. Banerjee⁹³, Sw. Banerjee¹⁶⁹, D. Banfi²⁹, A. Bangert¹³⁷, V. Bansal¹⁶⁹, H.S. Bansil¹⁷, L. Barak¹⁷¹, S.P. Baranov⁹⁴, A. Barashkou⁶⁵, A. Barbaro Galtieri¹⁴, T. Barber²⁷, E.L. Barberio⁸⁶, D. Barberis^{50a,50b}, M. Barbero²⁰, D.Y. Bardin⁶⁵, T. Barillari⁹⁹, M. Barisonzi¹⁷⁴, T. Barklow¹⁴³, N. Barlow²⁷, B.M. Barnett¹²⁹, R.M. Barnett¹⁴, A. Baroncelli^{134a}, A.J. Barr¹¹⁸, F. Barreiro⁸⁰, J. Barreiro Guimarães da Costa⁵⁷, P. Barrillon¹¹⁵, R. Bartoldus¹⁴³, A.E. Barton⁷¹, D. Bartsch²⁰, V. Bartsch¹⁴⁹, R.L. Bates⁵³, L. Batkova^{144a}, J.R. Batley²⁷, A. Battaglia¹⁶, M. Battistin²⁹, G. Battistoni^{89a}, F. Bauer¹³⁶, H.S. Bawa^{143,f}, B. Beare¹⁵⁸, T. Beau⁷⁸, P.H. Beauchemin¹¹⁸, R. Beccherle^{50a}, P. Bechtel⁴¹, H.P. Beck¹⁶, M. Beckingham⁴⁸, K.H. Becks¹⁷⁴, A.J. Beddall^{18c}, A. Beddall^{18c}, S. Bedikian¹⁷⁵, V.A. Bednyakov⁶⁵, C.P. Bee⁸³, M. Begel²⁴, S. Behar Harpaz¹⁵², P.K. Behera⁶³, M. Beimforde⁹⁹,

C. Belanger-Champagne¹⁶⁶, P.J. Bell⁴⁹, W.H. Bell⁴⁹, G. Bella¹⁵³,
 L. Bellagamba^{19a}, F. Bellina²⁹, M. Bellomo^{119a}, A. Belloni⁵⁷,
 O. Beloborodova¹⁰⁷, K. Belotskiy⁹⁶, O. Beltramello²⁹, S. Ben Ami¹⁵²,
 O. Benary¹⁵³, D. Benchekroun^{135a}, C. Benchouk⁸³, M. Bendel⁸¹,
 B.H. Benedict¹⁶³, N. Benekos¹⁶⁵, Y. Benhammou¹⁵³, D.P. Benjamin⁴⁴,
 M. Benoit¹¹⁵, J.R. Bensinger²², S. Bentvelsen¹⁰⁵, D. Berge²⁹,
 E. Bergeaas Kuutmann⁴¹, N. Berger⁴, F. Berghaus¹⁶⁹, E. Berglund⁴⁹,
 J. Beringer¹⁴, K. Bernardet⁸³, P. Bernat⁷⁷, R. Bernhard⁴⁸, C. Bernius²⁴,
 T. Berry⁷⁶, A. Bertin^{19a,19b}, F. Bertinelli²⁹, F. Bertolucci^{122a,122b},
 M.I. Besana^{89a,89b}, N. Besson¹³⁶, S. Bethke⁹⁹, W. Bhimji⁴⁵, R.M. Bianchi²⁹,
 M. Bianco^{72a,72b}, O. Biebel⁹⁸, S.P. Bieniek⁷⁷, J. Biesiada¹⁴, M. Biglietti^{134a,134b},
 H. Bilokon⁴⁷, M. Bindi^{19a,19b}, S. Binet¹¹⁵, A. Bingul^{18c}, C. Bini^{132a,132b},
 C. Biscarat¹⁷⁷, U. Bitenc⁴⁸, K.M. Black²¹, R.E. Blair⁵, J.-B. Blanchard¹¹⁵,
 G. Blanchot²⁹, T. Blazek^{144a}, C. Blocker²², J. Blocki³⁸, A. Blondel⁴⁹,
 W. Blum⁸¹, U. Blumenschein⁵⁴, G.J. Bobbink¹⁰⁵, V.B. Bobrovnikov¹⁰⁷,
 S.S. Bocchetta⁷⁹, A. Bocci⁴⁴, C.R. Boddy¹¹⁸, M. Boehler⁴¹, J. Boek¹⁷⁴,
 N. Boelaert³⁵, S. Böser⁷⁷, J.A. Bogaerts²⁹, A. Bogdanchikov¹⁰⁷,
 A. Bogouch^{90,*}, C. Bohm^{146a}, V. Boisvert⁷⁶, T. Bold^{163,g}, V. Boldea^{25a},
 N.M. Bolnet¹³⁶, M. Bona⁷⁵, V.G. Bondarenko⁹⁶, M. Boonekamp¹³⁶,
 G. Boorman⁷⁶, C.N. Booth¹³⁹, S. Bordini⁷⁸, C. Borer¹⁶, A. Borisov¹²⁸,
 G. Borissov⁷¹, I. Borjanovic^{12a}, S. Borroni^{132a,132b}, K. Bos¹⁰⁵, D. Boscherini^{19a},
 M. Bosman¹¹, H. Boterenbrood¹⁰⁵, D. Botterill¹²⁹, J. Bouchami⁹³,
 J. Boudreau¹²³, E.V. Bouhova-Thacker⁷¹, C. Boulahouache¹²³,
 C. Bourdarios¹¹⁵, N. Bousson⁸³, A. Boveia³⁰, J. Boyd²⁹, I.R. Boyko⁶⁵,
 N.I. Bozhko¹²⁸, I. Bozovic-Jelisavcic^{12b}, J. Bracinik¹⁷, A. Braem²⁹,
 P. Branchini^{134a}, G.W. Brandenburg⁵⁷, A. Brandt⁷, G. Brandt¹⁵, O. Brandt⁵⁴,
 U. Bratzler¹⁵⁶, B. Brau⁸⁴, J.E. Brau¹¹⁴, H.M. Braun¹⁷⁴, B. Brelrier¹⁵⁸,
 J. Bremer²⁹, R. Brenner¹⁶⁶, S. Bressler¹⁵², D. Breton¹¹⁵, D. Britton⁵³,
 F.M. Brochu²⁷, I. Brock²⁰, R. Brock⁸⁸, T.J. Brodbeck⁷¹, E. Brodet¹⁵³,
 F. Broggi^{89a}, C. Bromberg⁸⁸, G. Brooijmans³⁴, W.K. Brooks^{31b}, G. Brown⁸²,
 H. Brown⁷, E. Brubaker³⁰, P.A. Bruckman de Renstrom³⁸, D. Bruncko^{144b},
 R. Bruneliere⁴⁸, S. Brunet⁶¹, A. Bruni^{19a}, G. Bruni^{19a}, M. Bruschi^{19a},
 T. Buanes¹³, F. Bucci⁴⁹, J. Buchanan¹¹⁸, N.J. Buchanan², P. Buchholz¹⁴¹,
 R.M. Buckingham¹¹⁸, A.G. Buckley⁴⁵, S.I. Buda^{25a}, I.A. Budagov⁶⁵,
 B. Budick¹⁰⁸, V. Büscher⁸¹, L. Bugge¹¹⁷, D. Buirra-Clark¹¹⁸, O. Bulekov⁹⁶,
 M. Bunse⁴², T. Buran¹¹⁷, H. Burckhart²⁹, S. Burdin⁷³, T. Burgess¹³,
 S. Burke¹²⁹, E. Busato³³, P. Bussey⁵³, C.P. Buszello¹⁶⁶, F. Butin²⁹,
 B. Butler¹⁴³, J.M. Butler²¹, C.M. Buttar⁵³, J.M. Butterworth⁷⁷,
 W. Buttinger²⁷, T. Byatt⁷⁷, S. Cabrera Urbán¹⁶⁷, D. Caforio^{19a,19b}, O. Cakir^{3a},
 P. Calafiura¹⁴, G. Calderini⁷⁸, P. Calfayan⁹⁸, R. Calkins¹⁰⁶, L.P. Caloba^{23a},
 R. Caloi^{132a,132b}, D. Calvet³³, S. Calvet³³, R. Camacho Toro³³, A. Camard⁷⁸,
 P. Camarri^{133a,133b}, M. Cambiaghi^{119a,119b}, D. Cameron¹¹⁷, J. Cammin²⁰,
 S. Campana²⁹, M. Campanelli⁷⁷, V. Canale^{102a,102b}, F. Canelli³⁰, A. Canepa^{159a},

J. Cantero⁸⁰, L. Capasso^{102a,102b}, M.D.M. Capeans Garrido²⁹, I. Caprini^{25a},
 M. Caprini^{25a}, D. Capriotti⁹⁹, M. Capua^{36a,36b}, R. Caputo¹⁴⁸, C. Caramarcu^{25a},
 R. Cardarelli^{133a}, T. Carli²⁹, G. Carlino^{102a}, L. Carminati^{89a,89b}, B. Caron^{159a},
 S. Caron⁴⁸, G.D. Carrillo Montoya¹⁷², A.A. Carter⁷⁵, J.R. Carter²⁷,
 J. Carvalho^{124a,h}, D. Casadei¹⁰⁸, M.P. Casado¹¹, M. Cascella^{122a,122b},
 C. Caso^{50a,50b,*}, A.M. Castaneda Hernandez¹⁷², E. Castaneda-Miranda¹⁷²,
 V. Castillo Gimenez¹⁶⁷, N.F. Castro^{124a}, G. Cataldi^{72a}, F. Cataneo²⁹,
 A. Catinaccio²⁹, J.R. Catmore⁷¹, A. Cattai²⁹, G. Cattani^{133a,133b},
 S. Caughron⁸⁸, D. Cauz^{164a,164c}, P. Cavalleri⁷⁸, D. Cavalli^{89a},
 M. Cavalli-Sforza¹¹, V. Cavasinni^{122a,122b}, A. Cazzato^{72a,72b}, F. Ceradini^{134a,134b},
 A.S. Cerqueira^{23a}, A. Cerri²⁹, L. Cerrito⁷⁵, F. Cerutti⁴⁷, S.A. Cetin^{18b},
 F. Cevenini^{102a,102b}, A. Chafaq^{135a}, D. Chakraborty¹⁰⁶, K. Chan²,
 B. Chapleau⁸⁵, J.D. Chapman²⁷, J.W. Chapman⁸⁷, E. Chareyre⁷⁸,
 D.G. Charlton¹⁷, V. Chavda⁸², S. Cheatham⁷¹, S. Chekanov⁵,
 S.V. Chekulaev^{159a}, G.A. Chelkov⁶⁵, M.A. Chelstowska¹⁰⁴, C. Chen⁶⁴,
 H. Chen²⁴, L. Chen², S. Chen^{32c}, T. Chen^{32c}, X. Chen¹⁷², S. Cheng^{32a},
 A. Cheplakov⁶⁵, V.F. Chepurinov⁶⁵, R. Cherkaoui El Moursli^{135e},
 V. Chernyatin²⁴, E. Cheu⁶, S.L. Cheung¹⁵⁸, L. Chevalier¹³⁶, G. Chiefari^{102a,102b},
 L. Chikovani⁵¹, J.T. Childers^{58a}, A. Chilingarov⁷¹, G. Chiodini^{72a},
 M.V. Chizhov⁶⁵, G. Choudalakis³⁰, S. Chouridou¹³⁷, I.A. Christidi⁷⁷,
 A. Christov⁴⁸, D. Chromek-Burckhart²⁹, M.L. Chu¹⁵¹, J. Chudoba¹²⁵,
 G. Ciapetti^{132a,132b}, K. Ciba³⁷, A.K. Ciftci^{3a}, R. Ciftci^{3a}, D. Cinca³³,
 V. Cindro⁷⁴, M.D. Ciobotaru¹⁶³, C. Ciocca^{19a,19b}, A. Ciocio¹⁴, M. Cirilli⁸⁷,
 M. Ciubancan^{25a}, A. Clark⁴⁹, P.J. Clark⁴⁵, W. Cleland¹²³, J.C. Clemens⁸³,
 B. Clement⁵⁵, C. Clement^{146a,146b}, R.W. Clift¹²⁹, Y. Coadou⁸³,
 M. Cobal^{164a,164c}, A. Coccaro^{50a,50b}, J. Cochran⁶⁴, P. Coe¹¹⁸, J.G. Cogan¹⁴³,
 J. Coggeshall¹⁶⁵, E. Cogneras¹⁷⁷, C.D. Cojocaru²⁸, J. Colas⁴, A.P. Colijn¹⁰⁵,
 C. Collard¹¹⁵, N.J. Collins¹⁷, C. Collins-Tooth⁵³, J. Collot⁵⁵, G. Colon⁸⁴,
 P. Conde Muño^{124a}, E. Coniavitis¹¹⁸, M.C. Conidi¹¹, M. Consonni¹⁰⁴,
 S. Constantinescu^{25a}, C. Conta^{119a,119b}, F. Conventi^{102a,i}, J. Cook²⁹,
 M. Cooke¹⁴, B.D. Cooper⁷⁷, A.M. Cooper-Sarkar¹¹⁸, N.J. Cooper-Smith⁷⁶,
 K. Copic³⁴, T. Cornelissen^{50a,50b}, M. Corradi^{19a}, F. Corriveau^{85,j},
 A. Cortes-Gonzalez¹⁶⁵, G. Cortiana⁹⁹, G. Costa^{89a}, M.J. Costa¹⁶⁷,
 D. Costanzo¹³⁹, T. Costin³⁰, D. Côté²⁹, R. Coura Torres^{23a}, L. Courneyea¹⁶⁹,
 G. Cowan⁷⁶, C. Cowden²⁷, B.E. Cox⁸², K. Cranmer¹⁰⁸, F. Crescioli^{122a,122b},
 M. Cristinziani²⁰, G. Crosetti^{36a,36b}, R. Crupi^{72a,72b}, S. Crépé-Renaudin⁵⁵,
 C.-M. Cuciuc^{25a}, C. Cuenca Almenar¹⁷⁵, T. Cuhadar Donszelmann¹³⁹,
 S. Cuneo^{50a,50b}, M. Curatolo⁴⁷, C.J. Curtis¹⁷, P. Cwetanski⁶¹, H. Czirr¹⁴¹,
 Z. Czyzchula¹¹⁷, S. D'Auria⁵³, M. D'Onofrio⁷³, A. D'Orazio^{132a,132b},
 A. Da Rocha Gesualdi Mello^{23a}, P.V.M. Da Silva^{23a}, C. Da Via⁸²,
 W. Dabrowski³⁷, A. Dahloff⁴⁸, T. Dai⁸⁷, C. Dallapiccola⁸⁴, M. Dam³⁵,
 M. Dameri^{50a,50b}, D.S. Damiani¹³⁷, H.O. Danielsson²⁹, D. Dannheim⁹⁹,
 V. Dao⁴⁹, G. Darbo^{50a}, G.L. Darlea^{25b}, C. Daum¹⁰⁵, J.P. Dauvergne²⁹,

W. Davey⁸⁶, T. Davidek¹²⁶, N. Davidson⁸⁶, R. Davidson⁷¹, M. Davies⁹³,
 A.R. Davison⁷⁷, E. Dawe¹⁴², I. Dawson¹³⁹, J.W. Dawson^{5,*}, R.K. Daya³⁹,
 K. De⁷, R. de Asmundis^{102a}, S. De Castro^{19a,19b},
 P.E. De Castro Faria Salgado²⁴, S. De Cecco⁷⁸, J. de Graat⁹⁸, N. De Groot¹⁰⁴,
 P. de Jong¹⁰⁵, C. De La Taille¹¹⁵, H. De la Torre⁸⁰, B. De Lotto^{164a,164c},
 L. De Mora⁷¹, L. De Nooij¹⁰⁵, M. De Oliveira Branco²⁹, D. De Pedis^{132a},
 P. de Saintignon⁵⁵, A. De Salvo^{132a}, U. De Sanctis^{164a,164c}, A. De Santo¹⁴⁹,
 J.B. De Vivie De Regie¹¹⁵, S. Dean⁷⁷, D.V. Dedovich⁶⁵, J. Degenhardt¹²⁰,
 M. Dehchar¹¹⁸, M. Deile⁹⁸, C. Del Papa^{164a,164c}, J. Del Peso⁸⁰,
 T. Del Prete^{122a,122b}, A. Dell'Acqua²⁹, L. Dell'Asta^{89a,89b}, M. Della Pietra^{102a,i},
 D. della Volpe^{102a,102b}, M. Delmastro²⁹, P. Delpierre⁸³, N. Delruelle²⁹,
 P.A. Delsart⁵⁵, C. Deluca¹⁴⁸, S. Demers¹⁷⁵, M. Demichev⁶⁵, B. Demirkoz^{11,k},
 J. Deng¹⁶³, S.P. Denisov¹²⁸, D. Derendarz³⁸, J.E. Derkaoui^{135d}, F. Derue⁷⁸,
 P. Dervan⁷³, K. Desch²⁰, E. Devetak¹⁴⁸, P.O. Deviveiros¹⁵⁸, A. Dewhurst¹²⁹,
 B. DeWilde¹⁴⁸, S. Dhaliwal¹⁵⁸, R. Dhullipudi^{24,l}, A. Di Ciaccio^{133a,133b},
 L. Di Ciaccio⁴, A. Di Girolamo²⁹, B. Di Girolamo²⁹, S. Di Luise^{134a,134b},
 A. Di Mattia⁸⁸, B. Di Micco²⁹, R. Di Nardo^{133a,133b}, A. Di Simone^{133a,133b},
 R. Di Sipio^{19a,19b}, M.A. Diaz^{31a}, F. Diblen^{18c}, E.B. Diehl⁸⁷, H. Dietl⁹⁹,
 J. Dietrich⁴⁸, T.A. Dietzsch^{58a}, S. Diglio¹¹⁵, K. Dindar Yagci³⁹, J. Dingfelder²⁰,
 C. Dionisi^{132a,132b}, P. Dita^{25a}, S. Dita^{25a}, F. Dittus²⁹, F. Djama⁸³,
 R. Djilkibaev¹⁰⁸, T. Djobava⁵¹, M.A.B. do Vale^{23a}, A. Do Valle Wemans^{124a},
 T.K.O. Doan⁴, M. Dobbs⁸⁵, R. Dobinson^{29,*}, D. Dobos⁴², E. Dobson²⁹,
 M. Dobson¹⁶³, J. Dodd³⁴, O.B. Dogan^{18a,*}, C. Doglioni¹¹⁸, T. Doherty⁵³,
 Y. Doi^{66,*}, J. Dolejsi¹²⁶, I. Dolenc⁷⁴, Z. Dolezal¹²⁶, B.A. Dolgoshein^{96,*},
 T. Dohmae¹⁵⁵, M. Donadelli^{23b}, M. Donega¹²⁰, J. Donini⁵⁵, J. Dopke²⁹,
 A. Doria^{102a}, A. Dos Anjos¹⁷², M. Dosil¹¹, A. Dotti^{122a,122b}, M.T. Dova⁷⁰,
 J.D. Dowell¹⁷, A.D. Doxiadis¹⁰⁵, A.T. Doyle⁵³, Z. Drasal¹²⁶, J. Drees¹⁷⁴,
 N. Dressnandt¹²⁰, H. Drevermann²⁹, C. Driouichi³⁵, M. Dris⁹, J. Dubbert⁹⁹,
 T. Dubbs¹³⁷, S. Dube¹⁴, E. Duchovni¹⁷¹, G. Duckeck⁹⁸, A. Dudarev²⁹,
 F. Dudziak⁶⁴, M. Dührssen²⁹, I.P. Duerdoth⁸², L. Duflot¹¹⁵, M-A. Dufour⁸⁵,
 M. Dunford²⁹, H. Duran Yildiz^{3b}, R. Duxfield¹³⁹, M. Dwuznik³⁷, F. Dydak²⁹,
 D. Dzahini⁵⁵, M. Düren⁵², W.L. Ebenstein⁴⁴, J. Ebke⁹⁸, S. Eckert⁴⁸,
 S. Eckweiler⁸¹, K. Edmonds⁸¹, C.A. Edwards⁷⁶, W. Ehrenfeld⁴¹, T. Ehrich⁹⁹,
 T. Eifert²⁹, G. Eigen¹³, K. Einsweiler¹⁴, E. Eisenhandler⁷⁵, T. Ekelof¹⁶⁶,
 M. El Kacimi^{135c}, M. Ellert¹⁶⁶, S. Elles⁴, F. Ellinghaus⁸¹, K. Ellis⁷⁵, N. Ellis²⁹,
 J. Elmsheuser⁹⁸, M. Elsing²⁹, R. Ely¹⁴, D. Emeliyanov¹²⁹, R. Engelmann¹⁴⁸,
 A. Engl⁹⁸, B. Epp⁶², A. Eppig⁸⁷, J. Erdmann⁵⁴, A. Ereditato¹⁶,
 D. Eriksson^{146a}, J. Ernst¹, M. Ernst²⁴, J. Ernwein¹³⁶, D. Errede¹⁶⁵,
 S. Errede¹⁶⁵, E. Ertel⁸¹, M. Escalier¹¹⁵, C. Escobar¹⁶⁷, X. Espinal Curull¹¹,
 B. Esposito⁴⁷, F. Etienne⁸³, A.I. Etienvre¹³⁶, E. Etzion¹⁵³, D. Evangelakou⁵⁴,
 H. Evans⁶¹, L. Fabbri^{19a,19b}, C. Fabre²⁹, R.M. Fakhruddinov¹²⁸, S. Falciano^{132a},
 A.C. Falou¹¹⁵, Y. Fang¹⁷², M. Fanti^{89a,89b}, A. Farbin⁷, A. Farilla^{134a},
 J. Farley¹⁴⁸, T. Farooque¹⁵⁸, S.M. Farrington¹¹⁸, P. Farthouat²⁹,

P. Fassnacht²⁹, D. Fassouliotis⁸, B. Fatholahzadeh¹⁵⁸, A. Favareto^{89a,89b},
 L. Fayard¹¹⁵, S. Fazio^{36a,36b}, R. Febbraro³³, P. Federic^{144a}, O.L. Fedin¹²¹,
 I. Fedorko²⁹, W. Fedorko⁸⁸, M. Fehling-Kaschek⁴⁸, L. Feligioni⁸³,
 D. Fellmann⁵, C.U. Felzmann⁸⁶, C. Feng^{32d}, E.J. Feng³⁰, A.B. Fenyuk¹²⁸,
 J. Ferencei^{144b}, J. Ferland⁹³, W. Fernando¹⁰⁹, S. Ferrag⁵³, J. Ferrando⁵³,
 V. Ferrara⁴¹, A. Ferrari¹⁶⁶, P. Ferrari¹⁰⁵, R. Ferrari^{119a}, A. Ferrer¹⁶⁷,
 M.L. Ferrer⁴⁷, D. Ferrere⁴⁹, C. Ferretti⁸⁷, A. Ferretto Parodi^{50a,50b},
 M. Fiascaris³⁰, F. Fiedler⁸¹, A. Filipčić⁷⁴, A. Filippas⁹, F. Filthaut¹⁰⁴,
 M. Fincke-Keeler¹⁶⁹, M.C.N. Fiolhais^{124a,h}, L. Fiorini¹⁶⁷, A. Firan³⁹,
 G. Fischer⁴¹, P. Fischer²⁰, M.J. Fisher¹⁰⁹, S.M. Fisher¹²⁹, C.J. Flacco¹⁶³,
 M. Flechl⁴⁸, I. Fleck¹⁴¹, J. Fleckner⁸¹, P. Fleischmann¹⁷³, S. Fleischmann¹⁷⁴,
 T. Flick¹⁷⁴, L.R. Flores Castillo¹⁷², M.J. Flowerdew⁹⁹, F. Föhlich^{58a},
 M. Fokitis⁹, T. Fonseca Martin¹⁶, D.A. Forbush¹³⁸, A. Formica¹³⁶, A. Forti⁸²,
 D. Fortin^{159a}, J.M. Foster⁸², D. Fournier¹¹⁵, A. Foussat²⁹, A.J. Fowler⁴⁴,
 K. Fowler¹³⁷, H. Fox⁷¹, P. Francavilla^{122a,122b}, S. Franchino^{119a,119b}, D. Francis²⁹,
 T. Frank¹⁷¹, M. Franklin⁵⁷, S. Franz²⁹, M. Fraternali^{119a,119b}, S. Fratina¹²⁰,
 S.T. French²⁷, R. Froeschl²⁹, D. Froidevaux²⁹, J.A. Frost²⁷, C. Fukunaga¹⁵⁶,
 E. Fullana Torregrosa²⁹, J. Fuster¹⁶⁷, C. Gabaldon²⁹, O. Gabizon¹⁷¹,
 T. Gadfort²⁴, S. Gadomski⁴⁹, G. Gagliardi^{50a,50b}, P. Gagnon⁶¹, C. Galea⁹⁸,
 E.J. Gallas¹¹⁸, M.V. Gallas²⁹, V. Gallo¹⁶, B.J. Gallop¹²⁹, P. Gallus¹²⁵,
 E. Galyaev⁴⁰, K.K. Gan¹⁰⁹, Y.S. Gao^{143,f}, V.A. Gapienko¹²⁸, A. Gaponenko¹⁴,
 F. Garberson¹⁷⁵, M. Garcia-Sciveres¹⁴, C. García¹⁶⁷, J.E. García Navarro⁴⁹,
 R.W. Gardner³⁰, N. Garelli²⁹, H. Garitaonandia¹⁰⁵, V. Garonne²⁹,
 J. Garvey¹⁷, C. Gatti⁴⁷, G. Gaudio^{119a}, O. Gaumer⁴⁹, B. Gaur¹⁴¹,
 L. Gauthier¹³⁶, I.L. Gavrilenko⁹⁴, C. Gay¹⁶⁸, G. Gaycken²⁰, J-C. Gayde²⁹,
 E.N. Gazis⁹, P. Ge^{32d}, C.N.P. Gee¹²⁹, D.A.A. Geerts¹⁰⁵, Ch. Geich-Gimbel²⁰,
 K. Gellerstedt^{146a,146b}, C. Gemme^{50a}, A. Gemmell⁵³, M.H. Genest⁹⁸,
 S. Gentile^{132a,132b}, M. George⁵⁴, S. George⁷⁶, P. Gerlach¹⁷⁴, A. Gershon¹⁵³,
 C. Geweniger^{58a}, H. Ghazlane^{135b}, P. Ghez⁴, N. Ghodbane³³, B. Giacobbe^{19a},
 S. Giagu^{132a,132b}, V. Giakoumopoulou⁸, V. Giangiobbe^{122a,122b}, F. Gianotti²⁹,
 B. Gibbard²⁴, A. Gibson¹⁵⁸, S.M. Gibson²⁹, L.M. Gilbert¹¹⁸, M. Gilchriese¹⁴,
 V. Gilewsky⁹¹, D. Gillberg²⁸, A.R. Gillman¹²⁹, D.M. Gingrich^{2,e},
 J. Ginzburg¹⁵³, N. Giokaris⁸, R. Giordano^{102a,102b}, F.M. Giorgi¹⁵,
 P. Giovannini⁹⁹, P.F. Giraud¹³⁶, D. Giugni^{89a}, M. Giunta^{132a,132b}, P. Giusti^{19a},
 B.K. Gjelsten¹¹⁷, L.K. Gladilin⁹⁷, C. Glasman⁸⁰, J. Glatzer⁴⁸, A. Glazov⁴¹,
 K.W. Glitza¹⁷⁴, G.L. Glonti⁶⁵, J. Godfrey¹⁴², J. Godlewski²⁹, M. Goebel⁴¹,
 T. Göpfert⁴³, C. Goeringer⁸¹, C. Gössling⁴², T. Göttert⁹⁹, S. Goldfarb⁸⁷,
 D. Goldin³⁹, T. Golling¹⁷⁵, S.N. Golovnia¹²⁸, A. Gomes^{124a,b},
 L.S. Gomez Fajardo⁴¹, R. Gonçalo⁷⁶, J. Goncalves Pinto Firmino Da Costa⁴¹,
 L. Gonella²⁰, A. Gonidec²⁹, S. Gonzalez¹⁷², S. González de la Hoz¹⁶⁷,
 M.L. Gonzalez Silva²⁶, S. Gonzalez-Sevilla⁴⁹, J.J. Goodson¹⁴⁸, L. Goossens²⁹,
 P.A. Gorbounov⁹⁵, H.A. Gordon²⁴, I. Gorelov¹⁰³, G. Gorfine¹⁷⁴, B. Gorini²⁹,
 E. Gorini^{72a,72b}, A. Gorišek⁷⁴, E. Gornicki³⁸, S.A. Gorokhov¹²⁸,

V.N. Goryachev¹²⁸, B. Gosdzik⁴¹, M. Gosselink¹⁰⁵, M.I. Gostkin⁶⁵,
 M. Gouanère⁴, I. Gough Eschrich¹⁶³, M. Gouighri^{135a}, D. Goujdami^{135c},
 M.P. Goulette⁴⁹, A.G. Goussiou¹³⁸, C. Goy⁴, I. Grabowska-Bold^{163.g},
 V. Grabski¹⁷⁶, P. Grafström²⁹, C. Grah¹⁷⁴, K.-J. Grah⁴¹, F. Grancagnolo^{72a},
 S. Grancagnolo¹⁵, V. Grassi¹⁴⁸, V. Gratchev¹²¹, N. Grau³⁴, H.M. Gray²⁹,
 J.A. Gray¹⁴⁸, E. Graziani^{134a}, O.G. Grebenyuk¹²¹, D. Greenfield¹²⁹,
 T. Greenshaw⁷³, Z.D. Greenwood^{24.l}, I.M. Gregor⁴¹, P. Grenier¹⁴³,
 E. Griesmayer⁴⁶, J. Griffiths¹³⁸, N. Grigalashvili⁶⁵, A.A. Grillo¹³⁷,
 S. Grinstein¹¹, Ph. Gris³³, Y.V. Grishkevich⁹⁷, J.-F. Grivaz¹¹⁵, J. Grognuz²⁹,
 M. Groh⁹⁹, E. Gross¹⁷¹, J. Grosse-Knetter⁵⁴, J. Groth-Jensen⁷⁹, K. Grybel¹⁴¹,
 V.J. Guarino⁵, D. Guest¹⁷⁵, C. Guicheney³³, A. Guida^{72a,72b}, T. Guillemin⁴,
 S. Guindon⁵⁴, H. Guler^{85.m}, J. Gunther¹²⁵, B. Guo¹⁵⁸, J. Guo³⁴, A. Gupta³⁰,
 Y. Gusakov⁶⁵, V.N. Gushchin¹²⁸, A. Gutierrez⁹³, P. Gutierrez¹¹¹,
 N. Guttman¹⁵³, O. Gutzwiller¹⁷², C. Guyot¹³⁶, C. Gwenlan¹¹⁸, C.B. Gwilliam⁷³,
 A. Haas¹⁴³, S. Haas²⁹, C. Haber¹⁴, R. Hackenberg²⁴, H.K. Hadavand³⁹,
 D.R. Hadley¹⁷, P. Haefner⁹⁹, F. Hahn²⁹, S. Haider²⁹, Z. Hajduk³⁸,
 H. Hakobyan¹⁷⁶, J. Haller⁵⁴, K. Hamacher¹⁷⁴, P. Hamal¹¹³, A. Hamilton⁴⁹,
 S. Hamilton¹⁶¹, H. Han^{32a}, L. Han^{32b}, K. Hanagaki¹¹⁶, M. Hance¹²⁰,
 C. Handel⁸¹, P. Hanke^{58a}, J.R. Hansen³⁵, J.B. Hansen³⁵, J.D. Hansen³⁵,
 P.H. Hansen³⁵, P. Hansson¹⁴³, K. Hara¹⁶⁰, G.A. Hare¹³⁷, T. Harenberg¹⁷⁴,
 S. Harkusha⁹⁰, D. Harper⁸⁷, R.D. Harrington²¹, O.M. Harris¹³⁸,
 K. Harrison¹⁷, J. Hartert⁴⁸, F. Hartjes¹⁰⁵, T. Haruyama⁶⁶, A. Harvey⁵⁶,
 S. Hasegawa¹⁰¹, Y. Hasegawa¹⁴⁰, S. Hassani¹³⁶, M. Hatch²⁹, D. Hauff⁹⁹,
 S. Haug¹⁶, M. Hauschild²⁹, R. Hauser⁸⁸, M. Havranek²⁰, B.M. Hawes¹¹⁸,
 C.M. Hawkes¹⁷, R.J. Hawkings²⁹, D. Hawkins¹⁶³, T. Hayakawa⁶⁷, D. Hayden⁷⁶,
 H.S. Hayward⁷³, S.J. Haywood¹²⁹, E. Hazen²¹, M. He^{32d}, S.J. Head¹⁷,
 V. Hedberg⁷⁹, L. Heelan⁷, S. Heim⁸⁸, B. Heinemann¹⁴, S. Heisterkamp³⁵,
 L. Helary⁴, M. Heldmann⁴⁸, M. Heller¹¹⁵, S. Hellman^{146a,146b}, C. Helsen¹¹,
 R.C.W. Henderson⁷¹, M. Henke^{58a}, A. Henrichs⁵⁴, A.M. Henriques Correia²⁹,
 S. Henrot-Versille¹¹⁵, F. Henry-Couannier⁸³, C. Hensel⁵⁴, T. Henß¹⁷⁴,
 C.M. Hernandez⁷, Y. Hernández Jiménez¹⁶⁷, R. Herrberg¹⁵,
 A.D. Hershenhorn¹⁵², G. Herten⁴⁸, R. Hertenberger⁹⁸, L. Hervas²⁹,
 N.P. Hessey¹⁰⁵, A. Hidvegi^{146a}, E. Higón-Rodríguez¹⁶⁷, D. Hill^{5,*}, J.C. Hill²⁷,
 N. Hill⁵, K.H. Hiller⁴¹, S. Hillert²⁰, S.J. Hillier¹⁷, I. Hinchliffe¹⁴, E. Hines¹²⁰,
 M. Hirose¹¹⁶, F. Hirsch⁴², D. Hirschbuehl¹⁷⁴, J. Hobbs¹⁴⁸, N. Hod¹⁵³,
 M.C. Hodgkinson¹³⁹, P. Hodgson¹³⁹, A. Hoecker²⁹, M.R. Hoefkamp¹⁰³,
 J. Hoffman³⁹, D. Hoffmann⁸³, M. Hohlfeld⁸¹, M. Holder¹⁴¹, A. Holmes¹¹⁸,
 S.O. Holmgren^{146a}, T. Holy¹²⁷, J.L. Holzbauer⁸⁸, Y. Homma⁶⁷, T.M. Hong¹²⁰,
 L. Hooft van Huysduynen¹⁰⁸, T. Horazdovsky¹²⁷, C. Horn¹⁴³, S. Horner⁴⁸,
 K. Horton¹¹⁸, J.-Y. Hostachy⁵⁵, S. Hou¹⁵¹, M.A. Houlden⁷³, A. Hoummada^{135a},
 J. Howarth⁸², D.F. Howell¹¹⁸, I. Hristova⁴¹, J. Hrivnac¹¹⁵, I. Hruska¹²⁵,
 T. Hryn'ova⁴, P.J. Hsu¹⁷⁵, S.-C. Hsu¹⁴, G.S. Huang¹¹¹, Z. Hubacek¹²⁷,
 F. Hubaut⁸³, F. Huegging²⁰, T.B. Huffman¹¹⁸, E.W. Hughes³⁴, G. Hughes⁷¹,

R.E. Hughes-Jones⁸², M. Huhtinen²⁹, P. Hurst⁵⁷, M. Hurwitz¹⁴,
 U. Husemann⁴¹, N. Huseynov^{65,n}, J. Huston⁸⁸, J. Huth⁵⁷, G. Iacobucci^{102a},
 G. Iakovidis⁹, M. Ibbotson⁸², I. Ibragimov¹⁴¹, R. Ichimiya⁶⁷,
 L. Iconomidou-Fayard¹¹⁵, J. Idarraga¹¹⁵, M. Idzik³⁷, P. Iengo^{102a,102b},
 O. Igonkina¹⁰⁵, Y. Ikegami⁶⁶, M. Ikeno⁶⁶, Y. Ilchenko³⁹, D. Iliadis¹⁵⁴,
 D. Imbault⁷⁸, M. Imhaeuser¹⁷⁴, M. Imori¹⁵⁵, T. Ince²⁰, J. Inigo-Golfin²⁹,
 P. Ioannou⁸, M. Iodice^{134a}, G. Ionescu⁴, A. Irles Quiles¹⁶⁷, K. Ishii⁶⁶,
 A. Ishikawa⁶⁷, M. Ishino⁶⁶, R. Ishmukhametov³⁹, C. Issever¹¹⁸, S. Istin^{18a},
 Y. Itoh¹⁰¹, A.V. Ivashin¹²⁸, W. Iwanski³⁸, H. Iwasaki⁶⁶, J.M. Izen⁴⁰,
 V. Izzo^{102a}, B. Jackson¹²⁰, J.N. Jackson⁷³, P. Jackson¹⁴³, M.R. Jaekel²⁹,
 V. Jain⁶¹, K. Jakobs⁴⁸, S. Jakobsen³⁵, J. Jakubek¹²⁷, D.K. Jana¹¹¹,
 E. Jankowski¹⁵⁸, E. Jansen⁷⁷, A. Jantsch⁹⁹, M. Janus²⁰, G. Jarlskog⁷⁹,
 L. Jeanty⁵⁷, K. Jelen³⁷, I. Jen-La Plante³⁰, P. Jenni²⁹, A. Jeremie⁴, P. Jež³⁵,
 S. Jézéquel⁴, M.K. Jha^{19a}, H. Ji¹⁷², W. Ji⁸¹, J. Jia¹⁴⁸, Y. Jiang^{32b},
 M. Jimenez Belenguer⁴¹, G. Jin^{32b}, S. Jin^{32a}, O. Jinnouchi¹⁵⁷,
 M.D. Joergensen³⁵, D. Joffe³⁹, L.G. Johansen¹³, M. Johansen^{146a,146b},
 K.E. Johansson^{146a}, P. Johansson¹³⁹, S. Johnert⁴¹, K.A. Johns⁶,
 K. Jon-And^{146a,146b}, G. Jones⁸², R.W.L. Jones⁷¹, T.W. Jones⁷⁷, T.J. Jones⁷³,
 O. Jonsson²⁹, C. Joram²⁹, P.M. Jorge^{124a,b}, J. Joseph¹⁴, X. Ju¹³⁰,
 V. Juranek¹²⁵, P. Jussel⁶², V.V. Kabachenko¹²⁸, S. Kabana¹⁶, M. Kaci¹⁶⁷,
 A. Kaczmarska³⁸, P. Kadlecik³⁵, M. Kado¹¹⁵, H. Kagan¹⁰⁹, M. Kagan⁵⁷,
 S. Kaiser⁹⁹, E. Kajomovitz¹⁵², S. Kalinin¹⁷⁴, L.V. Kalinovskaya⁶⁵, S. Kama³⁹,
 N. Kanaya¹⁵⁵, M. Kaneda¹⁵⁵, T. Kanno¹⁵⁷, V.A. Kantserov⁹⁶, J. Kanzaki⁶⁶,
 B. Kaplan¹⁷⁵, A. Kapliy³⁰, J. Kaplon²⁹, D. Kar⁴³, M. Karagoz¹¹⁸,
 M. Karnevskiy⁴¹, K. Karr⁵, V. Kartvelishvili⁷¹, A.N. Karyukhin¹²⁸,
 L. Kashif¹⁷², A. Kasmi³⁹, R.D. Kass¹⁰⁹, A. Kastanas¹³, M. Kataoka⁴,
 Y. Kataoka¹⁵⁵, E. Katsoufis⁹, J. Katzy⁴¹, V. Kaushik⁶, K. Kawagoe⁶⁷,
 T. Kawamoto¹⁵⁵, G. Kawamura⁸¹, M.S. Kayl¹⁰⁵, V.A. Kazanin¹⁰⁷,
 M.Y. Kazarinov⁶⁵, J.R. Keates⁸², R. Keeler¹⁶⁹, R. Kehoe³⁹, M. Keil⁵⁴,
 G.D. Kekelidze⁶⁵, M. Kelly⁸², J. Kennedy⁹⁸, C.J. Kenney¹⁴³, M. Kenyon⁵³,
 O. Kepka¹²⁵, N. Kerschen²⁹, B.P. Kerševan⁷⁴, S. Kersten¹⁷⁴, K. Kessoku¹⁵⁵,
 C. Ketterer⁴⁸, J. Keung¹⁵⁸, M. Khakzad²⁸, F. Khalil-zada¹⁰,
 H. Khandanyan¹⁶⁵, A. Khanov¹¹², D. Kharchenko⁶⁵, A. Khodinov⁹⁶,
 A.G. Kholodenko¹²⁸, A. Khomich^{58a}, T.J. Khoo²⁷, G. Khoriali²⁰,
 A. Khoroshilov¹⁷⁴, N. Khovanskiy⁶⁵, V. Khovanskiy⁹⁵, E. Khramov⁶⁵,
 J. Khubua⁵¹, H. Kim⁷, M.S. Kim², P.C. Kim¹⁴³, S.H. Kim¹⁶⁰, N. Kimura¹⁷⁰,
 O. Kind¹⁵, B.T. King⁷³, M. King⁶⁷, R.S.B. King¹¹⁸, J. Kirk¹²⁹, G.P. Kirsch¹¹⁸,
 L.E. Kirsch²², A.E. Kiryunin⁹⁹, D. Kisielewska³⁷, T. Kittelmann¹²³,
 A.M. Kiver¹²⁸, H. Kiyamura⁶⁷, E. Kladiva^{144b}, J. Klaiber-Lodewigs⁴²,
 M. Klein⁷³, U. Klein⁷³, K. Kleinknecht⁸¹, M. Klemetti⁸⁵, A. Klier¹⁷¹,
 A. Klimentov²⁴, R. Klingenberg⁴², E.B. Klinkby³⁵, T. Klioutchnikova²⁹,
 P.F. Klok¹⁰⁴, S. Klous¹⁰⁵, E.-E. Kluge^{58a}, T. Kluge⁷³, P. Kluit¹⁰⁵, S. Kluth⁹⁹,
 E. Kneringer⁶², J. Knobloch²⁹, E.B.F.G. Knoops⁸³, A. Knue⁵⁴, B.R. Ko⁴⁴,

T. Kobayashi¹⁵⁵, M. Kobel⁴³, B. Koblitz²⁹, M. Kocian¹⁴³, A. Kocnar¹¹³,
 P. Kodys¹²⁶, K. Köneke²⁹, A.C. König¹⁰⁴, S. Koenig⁸¹, L. Köpke⁸¹,
 F. Koetsveld¹⁰⁴, P. Koevesarki²⁰, T. Koffas²⁹, E. Koffeman¹⁰⁵, F. Kohn⁵⁴,
 Z. Kohout¹²⁷, T. Kohriki⁶⁶, T. Koi¹⁴³, T. Kokott²⁰, G.M. Kolachev¹⁰⁷,
 H. Kolanoski¹⁵, V. Kolesnikov⁶⁵, I. Koletsou^{89a}, J. Koll⁸⁸, D. Kollar²⁹,
 M. Kollefrath⁴⁸, S.D. Kolya⁸², A.A. Komar⁹⁴, J.R. Komaragiri¹⁴², T. Kondo⁶⁶,
 T. Kono^{41,o}, A.I. Kononov⁴⁸, R. Konoplich^{108,p}, N. Konstantinidis⁷⁷,
 A. Kootz¹⁷⁴, S. Koperny³⁷, S.V. Kopikov¹²⁸, K. Korcyl³⁸, K. Kordas¹⁵⁴,
 V. Koreshev¹²⁸, A. Korn¹⁴, A. Korol¹⁰⁷, I. Korolkov¹¹, E.V. Korolkova¹³⁹,
 V.A. Korotkov¹²⁸, O. Kortner⁹⁹, S. Kortner⁹⁹, V.V. Kostyukhin²⁰,
 M.J. Kotamäki²⁹, S. Kotov⁹⁹, V.M. Kotov⁶⁵, A. Kotwal⁴⁴, C. Kourkoumelis⁸,
 V. Kouskoura¹⁵⁴, A. Koutsman¹⁰⁵, R. Kowalewski¹⁶⁹, T.Z. Kowalski³⁷,
 W. Kozanecki¹³⁶, A.S. Kozhin¹²⁸, V. Kral¹²⁷, V.A. Kramarenko⁹⁷,
 G. Kramberger⁷⁴, O. Krasel⁴², M.W. Krasny⁷⁸, A. Krasznahorkay¹⁰⁸,
 J. Kraus⁸⁸, A. Kreisel¹⁵³, F. Krejci¹²⁷, J. Kretzschmar⁷³, N. Krieger⁵⁴,
 P. Krieger¹⁵⁸, K. Kroeninger⁵⁴, H. Kroha⁹⁹, J. Kroll¹²⁰, J. Kroseberg²⁰,
 J. Krstic^{12a}, U. Kruchonak⁶⁵, H. Krüger²⁰, Z.V. Krumshteyn⁶⁵, A. Kruth²⁰,
 T. Kubota¹⁵⁵, S. Kuehn⁴⁸, A. Kugel^{58c}, T. Kuhl¹⁷⁴, D. Kuhn⁶², V. Kukhtin⁶⁵,
 Y. Kulchitsky⁹⁰, S. Kuleshov^{31b}, C. Kummer⁹⁸, M. Kuna⁷⁸, N. Kundu¹¹⁸,
 J. Kunkle¹²⁰, A. Kupco¹²⁵, H. Kurashige⁶⁷, M. Kurata¹⁶⁰, Y.A. Kurochkin⁹⁰,
 V. Kus¹²⁵, W. Kuykendall¹³⁸, M. Kuze¹⁵⁷, P. Kuzhir⁹¹, O. Kvasnicka¹²⁵,
 J. Kvita²⁹, R. Kwee¹⁵, A. La Rosa²⁹, L. La Rotonda^{36a,36b}, L. Labarga⁸⁰,
 J. Labbe⁴, S. Lablak^{135a}, C. Lacasta¹⁶⁷, F. Lacava^{132a,132b}, H. Lacker¹⁵,
 D. Lacour⁷⁸, V.R. Lacuesta¹⁶⁷, E. Ladygin⁶⁵, R. Lafaye⁴, B. Laforge⁷⁸,
 T. Lagouri⁸⁰, S. Lai⁴⁸, E. Laisne⁵⁵, M. Lamanna²⁹, C.L. Lampen⁶, W. Lampl⁶,
 E. Lancon¹³⁶, U. Landgraf⁴⁸, M.P.J. Landon⁷⁵, H. Landsman¹⁵², J.L. Lane⁸²,
 C. Lange⁴¹, A.J. Lankford¹⁶³, F. Lanni²⁴, K. Lantzsich²⁹, V.V. Lapin^{128,*},
 S. Laplace⁷⁸, C. Lapoire²⁰, J.F. Laporte¹³⁶, T. Lari^{89a}, A.V. Larionov¹²⁸,
 A. Larner¹¹⁸, C. Lasseur²⁹, M. Lassnig²⁹, W. Lau¹¹⁸, P. Laurelli⁴⁷,
 A. Lavorato¹¹⁸, W. Lavrijsen¹⁴, P. Laycock⁷³, A.B. Lazarev⁶⁵, A. Lazzaro^{89a,89b},
 O. Le Dortz⁷⁸, E. Le Guirriec⁸³, C. Le Maner¹⁵⁸, E. Le Menedeu¹³⁶,
 A. Lebedev⁶⁴, C. Lebel⁹³, T. LeCompte⁵, F. Ledroit-Guillon⁵⁵, H. Lee¹⁰⁵,
 J.S.H. Lee¹⁵⁰, S.C. Lee¹⁵¹, L. Lee¹⁷⁵, M. Lefebvre¹⁶⁹, M. Legendre¹³⁶,
 A. Leger⁴⁹, B.C. LeGeyt¹²⁰, F. Legger⁹⁸, C. Leggett¹⁴, M. Lehmacher²⁰,
 G. Lehmann Miotto²⁹, X. Lei⁶, M.A.L. Leite^{23b}, R. Leitner¹²⁶, D. Lellouch¹⁷¹,
 J. Lellouch⁷⁸, M. Leltchouk³⁴, V. Lendermann^{58a}, K.J.C. Leney^{145b}, T. Lenz¹⁷⁴,
 G. Lenzen¹⁷⁴, B. Lenzi¹³⁶, K. Leonhardt⁴³, S. Leontsinis⁹, C. Leroy⁹³,
 J-R. Lessard¹⁶⁹, J. Lesser^{146a}, C.G. Lester²⁷, A. Leung Fook Cheong¹⁷²,
 J. Levêque⁴, D. Levin⁸⁷, L.J. Levinson¹⁷¹, M.S. Levitski¹²⁸, M. Lewandowska²¹,
 A. Lewis¹¹⁸, G.H. Lewis¹⁰⁸, A.M. Leyko²⁰, M. Leyton¹⁵, B. Li⁸³, H. Li¹⁷²,
 S. Li^{32b,d}, X. Li⁸⁷, Z. Liang³⁹, Z. Liang^{118,q}, B. Liberti^{133a}, P. Lichard²⁹,
 M. Lichtnecker⁹⁸, K. Lie¹⁶⁵, W. Liebig¹³, R. Lifshitz¹⁵², J.N. Lilley¹⁷,
 C. Limbach²⁰, A. Limosani⁸⁶, M. Limper⁶³, S.C. Lin^{151,r}, F. Linde¹⁰⁵,

J.T. Linnemann⁸⁸, E. Lipeles¹²⁰, L. Lipinsky¹²⁵, A. Lipniacka¹³, T.M. Liss¹⁶⁵,
 D. Lissauer²⁴, A. Lister⁴⁹, A.M. Litke¹³⁷, C. Liu²⁸, D. Liu^{151,s}, H. Liu⁸⁷,
 J.B. Liu⁸⁷, M. Liu^{32b}, S. Liu², Y. Liu^{32b}, M. Livan^{119a,119b}, S.S.A. Livermore¹¹⁸,
 A. Lleres⁵⁵, J. Llorente Merino⁸⁰, S.L. Lloyd⁷⁵, E. Lobodzinska⁴¹, P. Loch⁶,
 W.S. Lockman¹³⁷, S. Lockwitz¹⁷⁵, T. Loddenkoetter²⁰, F.K. Loebinger⁸²,
 A. Loginov¹⁷⁵, C.W. Loh¹⁶⁸, T. Lohse¹⁵, K. Lohwasser⁴⁸, M. Lokajicek¹²⁵,
 J. Loken¹¹⁸, V.P. Lombardo⁴, R.E. Long⁷¹, L. Lopes^{124a,b},
 D. Lopez Mateos^{34,t}, M. Losada¹⁶², P. Loscutoff¹⁴, F. Lo Sterzo^{132a,132b},
 M.J. Losty^{159a}, X. Lou⁴⁰, A. Lounis¹¹⁵, K.F. Loureiro¹⁶², J. Love²¹,
 P.A. Love⁷¹, A.J. Lowe^{143,f}, F. Lu^{32a}, L. Lu³⁹, H.J. Lubatti¹³⁸, C. Luci^{132a,132b},
 A. Lucotte⁵⁵, A. Ludwig⁴³, D. Ludwig⁴¹, I. Ludwig⁴⁸, J. Ludwig⁴⁸,
 F. Luehring⁶¹, G. Luijckx¹⁰⁵, D. Lumb⁴⁸, L. Luminari^{132a}, E. Lund¹¹⁷,
 B. Lund-Jensen¹⁴⁷, B. Lundberg⁷⁹, J. Lundberg^{146a,146b}, J. Lundquist³⁵,
 M. Lungwitz⁸¹, A. Lupi^{122a,122b}, G. Lutz⁹⁹, D. Lynn²⁴, J. Lys¹⁴, E. Lytken⁷⁹,
 H. Ma²⁴, L.L. Ma¹⁷², J.A. Macana Goia⁹³, G. Maccarrone⁴⁷, A. Macchiolo⁹⁹,
 B. Maček⁷⁴, J. Machado Miguens^{124a}, D. Macina⁴⁹, R. Mackeprang³⁵,
 R.J. Madaras¹⁴, W.F. Mader⁴³, R. Maenner^{58c}, T. Maeno²⁴, P. Mättig¹⁷⁴,
 S. Mättig⁴¹, P.J. Magalhaes Martins^{124a,h}, L. Magnoni²⁹, E. Magradze⁵⁴,
 Y. Mahalalel¹⁵³, K. Mahboubi⁴⁸, G. Mahout¹⁷, C. Maiani^{132a,132b},
 C. Maidantchik^{23a}, A. Maio^{124a,b}, S. Majewski²⁴, Y. Makida⁶⁶, N. Makovec¹¹⁵,
 P. Mal⁶, Pa. Malecki³⁸, P. Malecki³⁸, V.P. Maleev¹²¹, F. Malek⁵⁵, U. Mallik⁶³,
 D. Malon⁵, S. Maltezos⁹, V. Malyshev¹⁰⁷, S. Malyukov²⁹, R. Mameghani⁹⁸,
 J. Mamuzic^{12b}, A. Manabe⁶⁶, L. Mandelli^{89a}, I. Mandić⁷⁴, R. Mandrysch¹⁵,
 J. Maneira^{124a}, P.S. Mangedard⁸⁸, I.D. Manjavidze⁶⁵, A. Mann⁵⁴,
 P.M. Manning¹³⁷, A. Manousakis-Katsikakis⁸, B. Mansoulie¹³⁶, A. Manz⁹⁹,
 A. Mapelli²⁹, L. Mapelli²⁹, L. March⁸⁰, J.F. Marchand²⁹, F. Marchese^{133a,133b},
 G. Marchiori⁷⁸, M. Marcisovsky¹²⁵, A. Marin^{21,*}, C.P. Marino⁶¹,
 F. Marroquim^{23a}, R. Marshall⁸², Z. Marshall²⁹, F.K. Martens¹⁵⁸,
 S. Marti-Garcia¹⁶⁷, A.J. Martin¹⁷⁵, B. Martin²⁹, B. Martin⁸⁸, F.F. Martin¹²⁰,
 J.P. Martin⁹³, Ph. Martin⁵⁵, T.A. Martin¹⁷, B. Martin dit Latour⁴⁹,
 M. Martinez¹¹, V. Martinez Outschoorn⁵⁷, A.C. Martyniuk⁸², M. Marx⁸²,
 F. Marzano^{132a}, A. Marzin¹¹¹, L. Masetti⁸¹, T. Mashimo¹⁵⁵, R. Mashinistov⁹⁴,
 J. Masik⁸², A.L. Maslennikov¹⁰⁷, M. Maß⁴², I. Massa^{19a,19b}, G. Massaro¹⁰⁵,
 N. Massol⁴, P. Mastrandrea^{132a,132b}, A. Mastroberardino^{36a,36b},
 T. Masubuchi¹⁵⁵, M. Mathes²⁰, P. Matricon¹¹⁵, H. Matsumoto¹⁵⁵,
 H. Matsunaga¹⁵⁵, T. Matsushita⁶⁷, C. Mattravers^{118,c}, J.M. Maugain²⁹,
 S.J. Maxfield⁷³, D.A. Maximov¹⁰⁷, E.N. May⁵, A. Mayne¹³⁹, R. Mazini¹⁵¹,
 M. Mazur²⁰, M. Mazzanti^{89a}, E. Mazzoni^{122a,122b}, S.P. Mc Kee⁸⁷,
 A. McCarn¹⁶⁵, R.L. McCarthy¹⁴⁸, T.G. McCarthy²⁸, N.A. McCubbin¹²⁹,
 K.W. McFarlane⁵⁶, J.A. Mcfayden¹³⁹, H. McGlone⁵³, G. Mchedlidze⁵¹,
 R.A. McLaren²⁹, T. Mclaughlan¹⁷, S.J. McMahan¹²⁹, R.A. McPherson^{169,j},
 A. Meade⁸⁴, J. Mechnich¹⁰⁵, M. Mechtel¹⁷⁴, M. Medinnis⁴¹,
 R. Meera-Lebbai¹¹¹, T. Meguro¹¹⁶, R. Mehdiyev⁹³, S. Mehlhase³⁵, A. Mehta⁷³,

K. Meier^{58a}, J. Meinhardt⁴⁸, B. Meirose⁷⁹, C. Melachrinou³⁰,
 B.R. Mellado Garcia¹⁷², L. Mendoza Navas¹⁶², Z. Meng^{151,s},
 A. Mengarelli^{19a,19b}, S. Menke⁹⁹, C. Menot²⁹, E. Meoni¹¹, K.M. Mercurio⁵⁷,
 P. Mermod¹¹⁸, L. Merola^{102a,102b}, C. Meroni^{89a}, F.S. Merritt³⁰, A. Messina²⁹,
 J. Metcalfe¹⁰³, A.S. Mete⁶⁴, S. Meuser²⁰, C. Meyer⁸¹, J.-P. Meyer¹³⁶,
 J. Meyer¹⁷³, J. Meyer⁵⁴, T.C. Meyer²⁹, W.T. Meyer⁶⁴, J. Miao^{32d}, S. Michal²⁹,
 L. Micu^{25a}, R.P. Middleton¹²⁹, P. Miele²⁹, S. Migas⁷³, L. Mijović⁴¹,
 G. Mikenberg¹⁷¹, M. Mikestikova¹²⁵, M. Mikuz⁷⁴, D.W. Miller¹⁴³,
 R.J. Miller⁸⁸, W.J. Mills¹⁶⁸, C. Mills⁵⁷, A. Milov¹⁷¹, D.A. Milstead^{146a,146b},
 D. Milstein¹⁷¹, A.A. Minaenko¹²⁸, M. Miñano¹⁶⁷, I.A. Minashvili⁶⁵,
 A.I. Mincer¹⁰⁸, B. Mindur³⁷, M. Mineev⁶⁵, Y. Ming¹³⁰, L.M. Mir¹¹,
 G. Mirabelli^{132a}, L. Miralles Verge¹¹, A. Misiejuk⁷⁶, J. Mitrevski¹³⁷,
 G.Y. Mitrofanov¹²⁸, V.A. Mitsou¹⁶⁷, S. Mitsui⁶⁶, P.S. Miyagawa⁸²,
 K. Miyazaki⁶⁷, J.U. Mjörnmark⁷⁹, T. Moa^{146a,146b}, P. Mockett¹³⁸, S. Moed⁵⁷,
 V. Moeller²⁷, K. Mönig⁴¹, N. Möser²⁰, S. Mohapatra¹⁴⁸, B. Mohn¹³,
 W. Mohr⁴⁸, S. Mohrdieck-Möck⁹⁹, A.M. Moisseev^{128,*}, R. Moles-Valls¹⁶⁷,
 J. Molina-Perez²⁹, J. Monk⁷⁷, E. Monnier⁸³, S. Montesano^{89a,89b},
 F. Monticelli⁷⁰, S. Monzani^{19a,19b}, R.W. Moore², G.F. Moorhead⁸⁶,
 C. Mora Herrera⁴⁹, A. Moraes⁵³, A. Morais^{124a,b}, N. Morange¹³⁶, J. Morel⁵⁴,
 G. Morello^{36a,36b}, D. Moreno⁸¹, M. Moreno Llácer¹⁶⁷, P. Morettini^{50a},
 M. Morii⁵⁷, J. Morin⁷⁵, Y. Morita⁶⁶, A.K. Morley²⁹, G. Mornacchi²⁹,
 M.-C. Morone⁴⁹, S.V. Morozov⁹⁶, J.D. Morris⁷⁵, H.G. Moser⁹⁹, M. Mosidze⁵¹,
 J. Moss¹⁰⁹, R. Mount¹⁴³, E. Mountricha⁹, S.V. Mouraviev⁹⁴, E.J.W. Moyse⁸⁴,
 M. Mudrinic^{12b}, F. Mueller^{58a}, J. Mueller¹²³, K. Mueller²⁰, T.A. Müller⁹⁸,
 D. Muenstermann²⁹, A. Muijs¹⁰⁵, A. Muir¹⁶⁸, Y. Munwes¹⁵³, K. Murakami⁶⁶,
 W.J. Murray¹²⁹, I. Mussche¹⁰⁵, E. Musto^{102a,102b}, A.G. Myagkov¹²⁸,
 M. Myska¹²⁵, J. Nadal¹¹, K. Nagai¹⁶⁰, K. Nagano⁶⁶, Y. Nagasaka⁶⁰,
 A.M. Nairz²⁹, Y. Nakahama¹¹⁵, K. Nakamura¹⁵⁵, I. Nakano¹¹⁰, G. Nanava²⁰,
 A. Napier¹⁶¹, M. Nash^{77,c}, N.R. Nation²¹, T. Nattermann²⁰, T. Naumann⁴¹,
 G. Navarro¹⁶², H.A. Neal⁸⁷, E. Nebot⁸⁰, P.Yu. Nechaeva⁹⁴, A. Negri^{119a,119b},
 G. Negri²⁹, S. Nektarijevic⁴⁹, A. Nelson⁶⁴, S. Nelson¹⁴³, T.K. Nelson¹⁴³,
 S. Nemecek¹²⁵, P. Nemethy¹⁰⁸, A.A. Nepomuceno^{23a}, M. Nessi^{29,u},
 S.Y. Nesterov¹²¹, M.S. Neubauer¹⁶⁵, A. Neusiedl⁸¹, R.M. Neves¹⁰⁸,
 P. Nevski²⁴, P.R. Newman¹⁷, R.B. Nickerson¹¹⁸, R. Nicolaidou¹³⁶,
 L. Nicolas¹³⁹, B. Nicquevert²⁹, F. Niedercorn¹¹⁵, J. Nielsen¹³⁷, T. Niinikoski²⁹,
 A. Nikiforov¹⁵, V. Nikolaenko¹²⁸, K. Nikolaev⁶⁵, I. Nikolic-Audit⁷⁸,
 K. Nikolopoulos²⁴, H. Nilsen⁴⁸, P. Nilsson⁷, Y. Ninomiya¹⁵⁵, A. Nisati^{132a},
 T. Nishiyama⁶⁷, R. Nisius⁹⁹, L. Nodulman⁵, M. Nomachi¹¹⁶, I. Nomidis¹⁵⁴,
 H. Nomoto¹⁵⁵, M. Nordberg²⁹, B. Nordkvist^{146a,146b}, P.R. Norton¹²⁹,
 J. Novakova¹²⁶, M. Nozaki⁶⁶, M. Nožička⁴¹, L. Nozka¹¹³, I.M. Nugent^{159a},
 A.-E. Nuncio-Quiroz²⁰, G. Nunes Hanninger²⁰, T. Nunnemann⁹⁸, E. Nurse⁷⁷,
 T. Nyman²⁹, B.J. O'Brien⁴⁵, S.W. O'Neale^{17,*}, D.C. O'Neil¹⁴², V. O'Shea⁵³,
 F.G. Oakham^{28,e}, H. Oberlack⁹⁹, J. Ocariz⁷⁸, A. Ochi⁶⁷, S. Oda¹⁵⁵, S. Odaka⁶⁶,

J. Odier⁸³, H. Ogren⁶¹, A. Oh⁸², S.H. Oh⁴⁴, C.C. Ohm^{146a,146b}, T. Ohshima¹⁰¹,
 H. Ohshita¹⁴⁰, T.K. Ohska⁶⁶, T. Ohsugi⁵⁹, S. Okada⁶⁷, H. Okawa¹⁶³,
 Y. Okumura¹⁰¹, T. Okuyama¹⁵⁵, M. Olcese^{50a}, A.G. Olchevski⁶⁵,
 M. Oliveira^{124a,h}, D. Oliveira Damazio²⁴, E. Oliver Garcia¹⁶⁷, D. Olivito¹²⁰,
 A. Olszewski³⁸, J. Olszowska³⁸, C. Omachi⁶⁷, A. Onofre^{124a,v}, P.U.E. Onyisi³⁰,
 C.J. Oram^{159a}, M.J. Oreglia³⁰, Y. Oren¹⁵³, D. Orestano^{134a,134b}, I. Orlov¹⁰⁷,
 C. Oropeza Barrera⁵³, R.S. Orr¹⁵⁸, E.O. Ortega¹³⁰, B. Osculati^{50a,50b},
 R. Ospanov¹²⁰, C. Osuna¹¹, G. Otero y Garzon²⁶, J.P. Ottersbach¹⁰⁵,
 M. Ouchrif^{135d}, F. Ould-Saada¹¹⁷, A. Ouraou¹³⁶, Q. Ouyang^{32a}, M. Owen⁸²,
 S. Owen¹³⁹, O.K. Øye¹³, V.E. Ozcan^{18a}, N. Ozturk⁷, A. Pacheco Pages¹¹,
 C. Padilla Aranda¹¹, E. Paganis¹³⁹, F. Paige²⁴, K. Pajchel¹¹⁷, S. Palestini²⁹,
 D. Pallin³³, A. Palma^{124a,b}, J.D. Palmer¹⁷, Y.B. Pan¹⁷², E. Panagiotopoulou⁹,
 B. Panes^{31a}, N. Panikashvili⁸⁷, S. Panitkin²⁴, D. Pantea^{25a}, M. Panuskova¹²⁵,
 V. Paolone¹²³, A. Papadelis^{146a}, Th.D. Papadopoulou⁹, A. Paramonov⁵,
 W. Park^{24,w}, M.A. Parker²⁷, F. Parodi^{50a,50b}, J.A. Parsons³⁴, U. Parzefall⁴⁸,
 E. Pasqualucci^{132a}, A. Passeri^{134a}, F. Pastore^{134a,134b}, Fr. Pastore²⁹, G. Pásztor^{49,x},
 S. Pataraiia¹⁷², N. Patel¹⁵⁰, J.R. Pater⁸², S. Patricelli^{102a,102b}, T. Pauly²⁹,
 M. Pecsny^{144a}, M.I. Pedraza Morales¹⁷², S.V. Peleganchuk¹⁰⁷, H. Peng¹⁷²,
 R. Pengo²⁹, A. Penson³⁴, J. Penwell⁶¹, M. Perantoni^{23a}, K. Perez^{34,t},
 T. Perez Cavalcanti⁴¹, E. Perez Codina¹¹, M.T. Pérez García-Estañ¹⁶⁷,
 V. Perez Reale³⁴, I. Peric²⁰, L. Perini^{89a,89b}, H. Pernegger²⁹, R. Perrino^{72a},
 P. Perrodo⁴, S. Persebe^{3a}, V.D. Peshekhonov⁶⁵, O. Peters¹⁰⁵,
 B.A. Petersen²⁹, J. Petersen²⁹, T.C. Petersen³⁵, E. Petit⁸³, A. Petridis¹⁵⁴,
 C. Petridou¹⁵⁴, E. Petrolo^{132a}, F. Petrucci^{134a,134b}, D. Petschull⁴¹,
 M. Petteni¹⁴², R. Pezoa^{31b}, A. Phan⁸⁶, A.W. Phillips²⁷, P.W. Phillips¹²⁹,
 G. Piacquadio²⁹, E. Piccaro⁷⁵, M. Piccinini^{19a,19b}, A. Pickford⁵³, S.M. Piec⁴¹,
 R. Piegaiia²⁶, J.E. Pilcher³⁰, A.D. Pilkington⁸², J. Pina^{124a,b},
 M. Pinamonti^{164a,164c}, A. Pinder¹¹⁸, J.L. Pinfold², J. Ping^{32c}, B. Pinto^{124a,b},
 O. Pirotte²⁹, C. Pizio^{89a,89b}, R. Placakyte⁴¹, M. Plamondon¹⁶⁹, W.G. Plano⁸²,
 M.-A. Pleier²⁴, A.V. Pleskach¹²⁸, A. Poblaguev²⁴, S. Poddar^{58a}, F. Podlyski³³,
 L. Poggioli¹¹⁵, T. Poghosyan²⁰, M. Pohl⁴⁹, F. Polci⁵⁵, G. Polesello^{119a},
 A. Policicchio¹³⁸, A. Polini^{19a}, J. Poll⁷⁵, V. Polychronakos²⁴,
 D.M. Pomarede¹³⁶, D. Pomeroy²², K. Pommès²⁹, L. Pontecorvo^{132a},
 B.G. Pope⁸⁸, G.A. Popeneciu^{25a}, D.S. Popovic^{12a}, A. Poppleton²⁹,
 X. Portell Bueso⁴⁸, R. Porter¹⁶³, C. Posch²¹, G.E. Pospelov⁹⁹, S. Pospisil¹²⁷,
 I.N. Potrap⁹⁹, C.J. Potter¹⁴⁹, C.T. Potter¹¹⁴, G. Poulard²⁹, J. Poveda¹⁷²,
 R. Prabhu⁷⁷, P. Pralavorio⁸³, S. Prasad⁵⁷, R. Pravahan⁷, S. Prell⁶⁴,
 K. Pretzl¹⁶, L. Pribyl²⁹, D. Price⁶¹, L.E. Price⁵, M.J. Price²⁹, P.M. Prichard⁷³,
 D. Prieur¹²³, M. Primavera^{72a}, K. Prokofiev¹⁰⁸, F. Prokoshin^{31b},
 S. Protopopescu²⁴, J. Proudfoot⁵, X. Prudent⁴³, H. Przysieznik⁴,
 S. Psoroulas²⁰, E. Ptacek¹¹⁴, J. Purdham⁸⁷, M. Purohit^{24,w}, P. Puzo¹¹⁵,
 Y. Pylypchenko¹¹⁷, J. Qian⁸⁷, Z. Qian⁸³, Z. Qin⁴¹, A. Quadt⁵⁴, D.R. Quarrie¹⁴,
 W.B. Quayle¹⁷², F. Quinonez^{31a}, M. Raas¹⁰⁴, V. Radescu^{58b}, B. Radics²⁰,

T. Rador^{18a}, F. Ragusa^{89a,89b}, G. Rahal¹⁷⁷, A.M. Rahimi¹⁰⁹, D. Rahm²⁴,
 S. Rajagopalan²⁴, M. Rammensee⁴⁸, M. Rammes¹⁴¹, M. Ramstedt^{146a,146b},
 K. Randrianarivony²⁸, P.N. Ratoff⁷¹, F. Rauscher⁹⁸, E. Rauter⁹⁹,
 M. Raymond²⁹, A.L. Read¹¹⁷, D.M. Rebuzzi^{119a,119b}, A. Redelbach¹⁷³,
 G. Redlinger²⁴, R. Reece¹²⁰, K. Reeves⁴⁰, A. Reichold¹⁰⁵,
 E. Reinherz-Aronis¹⁵³, A. Reinsch¹¹⁴, I. Reisinger⁴², D. Reljic^{12a},
 C. Rembser²⁹, Z.L. Ren¹⁵¹, A. Renaud¹¹⁵, P. Renkel³⁹, B. Rensch³⁵,
 M. Rescigno^{132a}, S. Resconi^{89a}, B. Resende¹³⁶, P. Reznicek⁹⁸, R. Rezvani¹⁵⁸,
 A. Richards⁷⁷, R. Richter⁹⁹, E. Richter-Was^{38,y}, M. Ridel⁷⁸, S. Rieke⁸¹,
 M. Rijpstra¹⁰⁵, M. Rijssenbeek¹⁴⁸, A. Rimoldi^{119a,119b}, L. Rinaldi^{19a},
 R.R. Rios³⁹, I. Riu¹¹, G. Rivoltella^{89a,89b}, F. Rizatdinova¹¹², E. Rizvi⁷⁵,
 S.H. Robertson^{85,j}, A. Robichaud-Veronneau⁴⁹, D. Robinson²⁷,
 J.E.M. Robinson⁷⁷, M. Robinson¹¹⁴, A. Robson⁵³, J.G. Rocha de Lima¹⁰⁶,
 C. Roda^{122a,122b}, D. Roda Dos Santos²⁹, S. Rodier⁸⁰, D. Rodriguez¹⁶²,
 Y. Rodriguez Garcia¹⁵, A. Roe⁵⁴, S. Roe²⁹, O. Røhne¹¹⁷, V. Rojo¹, S. Rolli¹⁶¹,
 A. Romaniouk⁹⁶, V.M. Romanov⁶⁵, G. Romeo²⁶, D. Romero Maltrana^{31a},
 L. Roos⁷⁸, E. Ros¹⁶⁷, S. Rosati^{132a,132b}, K. Rosbach⁴⁹, M. Rose⁷⁶,
 G.A. Rosenbaum¹⁵⁸, E.I. Rosenberg⁶⁴, P.L. Rosendahl¹³, L. Rosselet⁴⁹,
 V. Rossetti¹¹, E. Rossi^{102a,102b}, L.P. Rossi^{50a}, L. Rossi^{89a,89b}, M. Rotaru^{25a},
 I. Roth¹⁷¹, J. Rothberg¹³⁸, D. Rousseau¹¹⁵, C.R. Royon¹³⁶, A. Rozanov⁸³,
 Y. Rozen¹⁵², X. Ruan¹¹⁵, I. Rubinskiy⁴¹, B. Ruckert⁹⁸, N. Ruckstuhl¹⁰⁵,
 V.I. Rud⁹⁷, G. Rudolph⁶², F. Rühr⁶, F. Ruggieri^{134a,134b}, A. Ruiz-Martinez⁶⁴,
 E. Rulikowska-Zarebska³⁷, V. Rumiantsev^{91,*}, L. Rummyantsev⁶⁵, K. Runge⁴⁸,
 O. Runolfsson²⁰, Z. Rurikova⁴⁸, N.A. Rusakovich⁶⁵, D.R. Rust⁶¹,
 J.P. Rutherford⁶, C. Ruwiedel¹⁴, P. Ruzicka¹²⁵, Y.F. Ryabov¹²¹,
 V. Ryadovikov¹²⁸, P. Ryan⁸⁸, M. Rybar¹²⁶, G. Rybkin¹¹⁵, N.C. Ryder¹¹⁸,
 S. Rzaeva¹⁰, A.F. Saavedra¹⁵⁰, I. Sadeh¹⁵³, H.F-W. Sadrozinski¹³⁷,
 R. Sadykov⁶⁵, F. Safai Tehrani^{132a,132b}, H. Sakamoto¹⁵⁵, G. Salamanna¹⁰⁵,
 A. Salamon^{133a}, M. Saleem¹¹¹, D. Salihagic⁹⁹, A. Salnikov¹⁴³, J. Salt¹⁶⁷,
 B.M. Salvachua Ferrando⁵, D. Salvatore^{36a,36b}, F. Salvatore¹⁴⁹, A. Salvucci¹⁰⁴,
 A. Salzburger²⁹, D. Sampsonidis¹⁵⁴, B.H. Samset¹¹⁷, H. Sandaker¹³,
 H.G. Sander⁸¹, M.P. Sanders⁹⁸, M. Sandhoff¹⁷⁴, T. Sandoval²⁷,
 R. Sandstroem¹⁰⁵, S. Sandvoss¹⁷⁴, D.P.C. Sankey¹²⁹, A. Sansoni⁴⁷,
 C. Santamarina Rios⁸⁵, C. Santoni³³, R. Santonico^{133a,133b}, H. Santos^{124a},
 J.G. Saraiva^{124a,b}, T. Sarangi¹⁷², E. Sarkisyan-Grinbaum⁷, F. Sarri^{122a,122b},
 G. Sartisohn¹⁷⁴, O. Sasaki⁶⁶, T. Sasaki⁶⁶, N. Sasao⁶⁸, I. Satsounkevitch⁹⁰,
 G. Sauvage⁴, J.B. Sauvan¹¹⁵, P. Savard^{158,e}, V. Savinov¹²³, D.O. Savu²⁹,
 P. Savva⁹, L. Sawyer^{24,l}, D.H. Saxon⁵³, L.P. SAYS³³, C. Sbarra^{19a,19b},
 A. Sbrizzi^{19a,19b}, O. Scallon⁹³, D.A. Scannichio¹⁶³, J. Schaarschmidt¹¹⁵,
 P. Schacht⁹⁹, U. Schäfer⁸¹, S. Schaepe²⁰, S. Schaetzel^{58b}, A.C. Schaffer¹¹⁵,
 D. Schaile⁹⁸, R.D. Schamberger¹⁴⁸, A.G. Schamov¹⁰⁷, V. Scharf^{58a},
 V.A. Schegelsky¹²¹, D. Scheirich⁸⁷, M.I. Scherzer¹⁴, C. Schiavi^{50a,50b},
 J. Schieck⁹⁸, M. Schioppa^{36a,36b}, S. Schlenker²⁹, J.L. Schlereth⁵, E. Schmidt⁴⁸,

M.P. Schmidt^{175,*}, K. Schmieden²⁰, C. Schmitt⁸¹, S. Schmitt^{58b}, M. Schmitz²⁰,
 A. Schöning^{58b}, M. Schott²⁹, D. Schouten¹⁴², J. Schovancova¹²⁵, M. Schram⁸⁵,
 C. Schroeder⁸¹, N. Schroer^{58c}, S. Schuh²⁹, G. Schuler²⁹, J. Schultes¹⁷⁴,
 H.-C. Schultz-Coulon^{58a}, H. Schulz¹⁵, J.W. Schumacher²⁰, M. Schumacher⁴⁸,
 B.A. Schumm¹³⁷, Ph. Schune¹³⁶, C. Schwanenberger⁸², A. Schwartzman¹⁴³,
 Ph. Schwemling⁷⁸, R. Schwienhorst⁸⁸, R. Schwierz⁴³, J. Schwindling¹³⁶,
 W.G. Scott¹²⁹, J. Searcy¹¹⁴, E. Sedykh¹²¹, E. Segura¹¹, S.C. Seidel¹⁰³,
 A. Seiden¹³⁷, F. Seifert⁴³, J.M. Seixas^{23a}, G. Sekhniadze^{102a},
 D.M. Seliverstov¹²¹, B. Sellden^{146a}, G. Sellers⁷³, M. Seman^{144b},
 N. Semprini-Cesari^{19a,19b}, C. Serfon⁹⁸, L. Serin¹¹⁵, R. Seuster⁹⁹, H. Severini¹¹¹,
 M.E. Sevier⁸⁶, A. Sfyrla²⁹, E. Shabalina⁵⁴, M. Shamim¹¹⁴, L.Y. Shan^{32a},
 J.T. Shank²¹, Q.T. Shao⁸⁶, M. Shapiro¹⁴, P.B. Shatalov⁹⁵, L. Shaver⁶,
 C. Shaw⁵³, K. Shaw^{164a,164c}, D. Sherman¹⁷⁵, P. Sherwood⁷⁷, A. Shibata¹⁰⁸,
 S. Shimizu²⁹, M. Shimojima¹⁰⁰, T. Shin⁵⁶, A. Shmeleva⁹⁴, M.J. Shochet³⁰,
 D. Short¹¹⁸, M.A. Shupe⁶, P. Sicho¹²⁵, A. Sidoti^{132a,132b}, A. Siebel¹⁷⁴,
 F. Siegert⁴⁸, J. Siegrist¹⁴, Dj. Sijacki^{12a}, O. Silbert¹⁷¹, J. Silva^{124a,b},
 Y. Silver¹⁵³, D. Silverstein¹⁴³, S.B. Silverstein^{146a}, V. Simak¹²⁷, O. Simard¹³⁶,
 Lj. Simic^{12a}, S. Simion¹¹⁵, B. Simmons⁷⁷, M. Simonyan³⁵, P. Sinervo¹⁵⁸,
 N.B. Sinev¹¹⁴, V. Sipica¹⁴¹, G. Siragusa⁸¹, A.N. Sisakyan⁶⁵, S.Yu. Sivoklokov⁹⁷,
 J. Sjölin^{146a,146b}, T.B. Sjusen¹³, L.A. Skinnari¹⁴, K. Skovpen¹⁰⁷, P. Skubic¹¹¹,
 N. Skvorodnev²², M. Slater¹⁷, T. Slavicek¹²⁷, K. Sliwa¹⁶¹, T.J. Sloan⁷¹,
 J. Sloper²⁹, V. Smakhtin¹⁷¹, S.Yu. Smirnov⁹⁶, L.N. Smirnova⁹⁷, O. Smirnova⁷⁹,
 B.C. Smith⁵⁷, D. Smith¹⁴³, K.M. Smith⁵³, M. Smizanska⁷¹, K. Smolek¹²⁷,
 A.A. Snesev⁹⁴, S.W. Snow⁸², J. Snow¹¹¹, J. Snuverink¹⁰⁵, S. Snyder²⁴,
 M. Soares^{124a}, R. Sobie^{169,j}, J. Sodomka¹²⁷, A. Soffer¹⁵³, C.A. Solans¹⁶⁷,
 M. Solar¹²⁷, J. Solc¹²⁷, E. Soldatov⁹⁶, U. Soldevila¹⁶⁷,
 E. Solfaroli Camillocci^{132a,132b}, A.A. Solodkov¹²⁸, O.V. Solovyanov¹²⁸,
 J. Sondericker²⁴, N. Soni², V. Sopko¹²⁷, B. Sopko¹²⁷, M. Sorbi^{89a,89b},
 M. Sosebee⁷, A. Soukharev¹⁰⁷, S. Spagnolo^{72a,72b}, F. Spanò³⁴, R. Spighi^{19a},
 G. Spigo²⁹, F. Spila^{132a,132b}, E. Spiriti^{134a}, R. Spiwoks²⁹, M. Spousta¹²⁶,
 T. Spreitzer¹⁵⁸, B. Spurlock⁷, R.D. St. Denis⁵³, T. Stahl¹⁴¹, J. Stahlman¹²⁰,
 R. Stamen^{58a}, E. Stanecka²⁹, R.W. Stanek⁵, C. Stanescu^{134a}, S. Stapnes¹¹⁷,
 E.A. Starchenko¹²⁸, J. Stark⁵⁵, P. Staroba¹²⁵, P. Starovoitov⁹¹, A. Staude⁹⁸,
 P. Stavina^{144a}, G. Stavropoulos¹⁴, G. Steele⁵³, P. Steinbach⁴³, P. Steinberg²⁴,
 I. Stekl¹²⁷, B. Stelzer¹⁴², H.J. Stelzer⁴¹, O. Stelzer-Chilton^{159a}, H. Stenzel⁵²,
 K. Stevenson⁷⁵, G.A. Stewart⁵³, J.A. Stillings²⁰, T. Stockmanns²⁰,
 M.C. Stockton²⁹, K. Stoerig⁴⁸, G. Stoica^{25a}, S. Stonjek⁹⁹, P. Strachota¹²⁶,
 A.R. Stradling⁷, A. Straessner⁴³, J. Strandberg¹⁴⁷, S. Strandberg^{146a,146b},
 A. Strandlie¹¹⁷, M. Strang¹⁰⁹, E. Strauss¹⁴³, M. Strauss¹¹¹, P. Strizenec^{144b},
 R. Ströhmer¹⁷³, D.M. Strom¹¹⁴, J.A. Strong^{76,*}, R. Stroynowski³⁹,
 J. Strube¹²⁹, B. Stugu¹³, I. Stumer^{24,*}, J. Stupak¹⁴⁸, P. Sturm¹⁷⁴,
 D.A. Soh^{151,q}, D. Su¹⁴³, HS. Subramania², A. Succurro¹¹, Y. Sugaya¹¹⁶,
 T. Sugimoto¹⁰¹, C. Suhr¹⁰⁶, K. Suita⁶⁷, M. Suk¹²⁶, V.V. Sulin⁹⁴,

S. Sultansoy^{3d}, T. Sumida²⁹, X. Sun⁵⁵, J.E. Sundermann⁴⁸, K. Suruliz^{164a,164b},
 S. Sushkov¹¹, G. Susinno^{36a,36b}, M.R. Sutton¹³⁹, Y. Suzuki⁶⁶, M. Svatos¹²⁵,
 Yu.M. Sviridov¹²⁸, S. Swedish¹⁶⁸, I. Sykora^{144a}, T. Sykora¹²⁶, B. Szeless²⁹,
 J. Sánchez¹⁶⁷, D. Ta¹⁰⁵, K. Tackmann⁴¹, A. Taffard¹⁶³, R. Tafirout^{159a},
 A. Taga¹¹⁷, N. Taiblum¹⁵³, Y. Takahashi¹⁰¹, H. Takai²⁴, R. Takashima⁶⁹,
 H. Takeda⁶⁷, T. Takeshita¹⁴⁰, M. Talby⁸³, A. Talyshev¹⁰⁷, M.C. Tamsett²⁴,
 J. Tanaka¹⁵⁵, R. Tanaka¹¹⁵, S. Tanaka¹³¹, S. Tanaka⁶⁶, Y. Tanaka¹⁰⁰, K. Tani⁶⁷,
 N. Tannoury⁸³, G.P. Tappern²⁹, S. Tapprogge⁸¹, D. Tardif¹⁵⁸, S. Tarem¹⁵²,
 F. Tarrade²⁴, G.F. Tartarelli^{89a}, P. Tas¹²⁶, M. Tasevsky¹²⁵, E. Tassi^{36a,36b},
 M. Tatarkhanov¹⁴, C. Taylor⁷⁷, F.E. Taylor⁹², G.N. Taylor⁸⁶, W. Taylor^{159b},
 M. Teixeira Dias Castanheira⁷⁵, P. Teixeira-Dias⁷⁶, K.K. Temming⁴⁸,
 H. Ten Kate²⁹, P.K. Teng¹⁵¹, S. Terada⁶⁶, K. Terashi¹⁵⁵, J. Terron⁸⁰,
 M. Terwort^{41,o}, M. Testa⁴⁷, R.J. Teuscher^{158,j}, J. Thadome¹⁷⁴, J. Therhaag²⁰,
 T. Theveneaux-Pelzer⁷⁸, M. Thioye¹⁷⁵, S. Thoma⁴⁸, J.P. Thomas¹⁷,
 E.N. Thompson⁸⁴, P.D. Thompson¹⁷, P.D. Thompson¹⁵⁸, A.S. Thompson⁵³,
 E. Thomson¹²⁰, M. Thomson²⁷, R.P. Thun⁸⁷, T. Tic¹²⁵, V.O. Tikhomirov⁹⁴,
 Y.A. Tikhonov¹⁰⁷, C.J.W.P. Timmermans¹⁰⁴, P. Tipton¹⁷⁵,
 F.J. Tique Aires Viegas²⁹, S. Tisserant⁸³, J. Tobias⁴⁸, B. Toczek³⁷,
 T. Todorov⁴, S. Todorova-Nova¹⁶¹, B. Toggerson¹⁶³, J. Tojo⁶⁶, S. Tokár^{144a},
 K. Tokunaga⁶⁷, K. Tokushuku⁶⁶, K. Tollefson⁸⁸, M. Tomoto¹⁰¹, L. Tompkins¹⁴,
 K. Toms¹⁰³, G. Tong^{32a}, A. Tonoyan¹³, C. Topfel¹⁶, N.D. Topilin⁶⁵,
 I. Torchiani²⁹, E. Torrence¹¹⁴, E. Torró Pastor¹⁶⁷, J. Toth^{83,x}, F. Touchard⁸³,
 D.R. Tovey¹³⁹, D. Traynor⁷⁵, T. Trefzger¹⁷³, J. Treis²⁰, L. Tremblet²⁹,
 A. Tricoli²⁹, I.M. Trigger^{159a}, S. Trincaz-Duvold⁷⁸, T.N. Trinh⁷⁸,
 M.F. Tripiana⁷⁰, W. Trischuk¹⁵⁸, A. Trivedi^{24,w}, B. Trocmé⁵⁵, C. Troncon^{89a},
 M. Trottier-McDonald¹⁴², A. Trzupek³⁸, C. Tsarouchas²⁹, J.C-L. Tseng¹¹⁸,
 M. Tsiakiris¹⁰⁵, P.V. Tsiareshka⁹⁰, D. Tsionou⁴, G. Tsipolitis⁹,
 V. Tsiskaridze⁴⁸, E.G. Tskhadadze⁵¹, I.I. Tsukerman⁹⁵, V. Tsulaia¹²³,
 J.-W. Tsung²⁰, S. Tsuno⁶⁶, D. Tsybychev¹⁴⁸, A. Tua¹³⁹, J.M. Tuggle³⁰,
 M. Turala³⁸, D. Turecek¹²⁷, I. Turk Cakir^{3e}, E. Turlay¹⁰⁵, R. Turra^{89a,89b},
 P.M. Tuts³⁴, A. Tykhonov⁷⁴, M. Tylmad^{146a,146b}, M. Tyndel¹²⁹, H. Tyrvainen²⁹,
 G. Tzanakos⁸, K. Uchida²⁰, I. Ueda¹⁵⁵, R. Ueno²⁸, M. Ugland¹³,
 M. Uhlenbrock²⁰, M. Uhrmacher⁵⁴, F. Ukegawa¹⁶⁰, G. Unal²⁹,
 D.G. Underwood⁵, A. Undrus²⁴, G. Unel¹⁶³, Y. Unno⁶⁶, D. Urbaniec³⁴,
 E. Urkovsky¹⁵³, P. Urrejola^{31a}, G. Usai⁷, M. Uslenghi^{119a,119b}, L. Vacavant⁸³,
 V. Vacek¹²⁷, B. Vachon⁸⁵, S. Vahsen¹⁴, J. Valenta¹²⁵, P. Valente^{132a},
 S. Valentineti^{19a,19b}, S. Valkar¹²⁶, E. Valladolid Gallego¹⁶⁷, S. Vallecorsa¹⁵²,
 J.A. Valls Ferrer¹⁶⁷, H. van der Graaf¹⁰⁵, E. van der Kraaij¹⁰⁵,
 R. Van Der Leeuw¹⁰⁵, E. van der Poel¹⁰⁵, D. van der Ster²⁹, B. Van Eijk¹⁰⁵,
 N. van Eldik⁸⁴, P. van Gemmeren⁵, Z. van Kesteren¹⁰⁵, I. van Vulpen¹⁰⁵,
 W. Vandelli²⁹, G. Vandoni²⁹, A. Vaniachine⁵, P. Vankov⁴¹, F. Vannucci⁷⁸,
 F. Varela Rodriguez²⁹, R. Vari^{132a}, E.W. Varnes⁶, D. Varouchas¹⁴,
 A. Vartapetian⁷, K.E. Varvell¹⁵⁰, V.I. Vassilakopoulos⁵⁶, F. Vazeille³³,

G. Vegni^{89a,89b}, J.J. Veillet¹¹⁵, C. Vellidis⁸, F. Veloso^{124a}, R. Veness²⁹,
 S. Veneziano^{132a}, A. Ventura^{72a,72b}, D. Ventura¹³⁸, M. Venturi⁴⁸, N. Venturi¹⁶,
 V. Vercesi^{119a}, M. Verducci¹³⁸, W. Verkerke¹⁰⁵, J.C. Vermeulen¹⁰⁵, A. Vest⁴³,
 M.C. Vetterli^{142,e}, I. Vichou¹⁶⁵, T. Vickey^{145b,z}, G.H.A. Viehhauser¹¹⁸,
 S. Viel¹⁶⁸, M. Villa^{19a,19b}, M. Villaplana Perez¹⁶⁷, E. Vilucchi⁴⁷,
 M.G. Vinciter²⁸, E. Vinek²⁹, V.B. Vinogradov⁶⁵, M. Virchaux^{136,*}, S. Viret³³,
 J. Virzi¹⁴, A. Vitale^{19a,19b}, O. Vitells¹⁷¹, M. Viti⁴¹, I. Vivarelli⁴⁸,
 F. Vives Vaque¹¹, S. Vlachos⁹, M. Vlasak¹²⁷, N. Vlasov²⁰, A. Vogel²⁰,
 P. Vokac¹²⁷, G. Volpi⁴⁷, M. Volpi¹¹, G. Volpini^{89a}, H. von der Schmitt⁹⁹,
 J. von Loeben⁹⁹, H. von Radziewski⁴⁸, E. von Toerne²⁰, V. Vorobel¹²⁶,
 A.P. Vorobiev¹²⁸, V. Vorwerk¹¹, M. Vos¹⁶⁷, R. Voss²⁹, T.T. Voss¹⁷⁴,
 J.H. Vosseveld⁷³, N. Vranjes^{12a}, M. Vranjes Milosavljevic^{12a}, V. Vrba¹²⁵,
 M. Vreeswijk¹⁰⁵, T. Vu Anh⁸¹, R. Vuillermet²⁹, I. Vukotic¹¹⁵, W. Wagner¹⁷⁴,
 P. Wagner¹²⁰, H. Wahlen¹⁷⁴, J. Wakabayashi¹⁰¹, J. Walbersloh⁴², S. Walch⁸⁷,
 J. Walder⁷¹, R. Walker⁹⁸, W. Walkowiak¹⁴¹, R. Wall¹⁷⁵, P. Waller⁷³,
 C. Wang⁴⁴, H. Wang¹⁷², H. Wang^{32b,aa}, J. Wang¹⁵¹, J. Wang^{32d}, J.C. Wang¹³⁸,
 R. Wang¹⁰³, S.M. Wang¹⁵¹, A. Warburton⁸⁵, C.P. Ward²⁷, M. Warsinsky⁴⁸,
 P.M. Watkins¹⁷, A.T. Watson¹⁷, M.F. Watson¹⁷, G. Watts¹³⁸, S. Watts⁸²,
 A.T. Waugh¹⁵⁰, B.M. Waugh⁷⁷, J. Weber⁴², M. Weber¹²⁹, M.S. Weber¹⁶,
 P. Weber⁵⁴, A.R. Weidberg¹¹⁸, P. Weigell⁹⁹, J. Weingarten⁵⁴, C. Weiser⁴⁸,
 H. Wellenstein²², P.S. Wells²⁹, M. Wen⁴⁷, T. Wenaus²⁴, S. Wendler¹²³,
 Z. Weng^{151,q}, T. Wengler²⁹, S. Wenig²⁹, N. Wermes²⁰, M. Werner⁴⁸,
 P. Werner²⁹, M. Werth¹⁶³, M. Wessels^{58a}, C. Weydert⁵⁵, K. Whalen²⁸,
 S.J. Wheeler-Ellis¹⁶³, S.P. Whitaker²¹, A. White⁷, M.J. White⁸⁶, S. White²⁴,
 S.R. Whitehead¹¹⁸, D. Whiteson¹⁶³, D. Whittington⁶¹, F. Wicek¹¹⁵,
 D. Wicke¹⁷⁴, F.J. Wickens¹²⁹, W. Wiedenmann¹⁷², M. Wielers¹²⁹,
 P. Wienemann²⁰, L.A.M. Wiik⁴⁸, P.A. Wijeratne⁷⁷, A. Wildauer¹⁶⁷,
 M.A. Wildt^{41,o}, I. Wilhelm¹²⁶, H.G. Wilkens²⁹, J.Z. Will⁹⁸, E. Williams³⁴,
 H.H. Williams¹²⁰, W. Willis³⁴, S. Willocq⁸⁴, J.A. Wilson¹⁷, M.G. Wilson¹⁴³,
 A. Wilson⁸⁷, I. Wingerter-Seez⁴, S. Winkelmann⁴⁸, F. Winklmeier²⁹,
 M. Wittgen¹⁴³, M.W. Wolter³⁸, H. Wolters^{124a,h}, G. Wooden¹¹⁸,
 B.K. Wosiek³⁸, J. Wotschack²⁹, M.J. Woudstra⁸⁴, K. Wraight⁵³, C. Wright⁵³,
 B. Wrona⁷³, S.L. Wu¹⁷², X. Wu⁴⁹, Y. Wu^{32b,ab}, E. Wulf³⁴, R. Wunstorff⁴²,
 B.M. Wynne⁴⁵, L. Xaplanteris⁹, S. Xella³⁵, S. Xie⁴⁸, Y. Xie^{32a}, C. Xu^{32b,ac},
 D. Xu¹³⁹, G. Xu^{32a}, B. Yabsley¹⁵⁰, M. Yamada⁶⁶, A. Yamamoto⁶⁶,
 K. Yamamoto⁶⁴, S. Yamamoto¹⁵⁵, T. Yamamura¹⁵⁵, J. Yamaoka⁴⁴,
 T. Yamazaki¹⁵⁵, Y. Yamazaki⁶⁷, Z. Yan²¹, H. Yang⁸⁷, U.K. Yang⁸², Y. Yang⁶¹,
 Y. Yang^{32a}, Z. Yang^{146a,146b}, S. Yanush⁹¹, W-M. Yao¹⁴, Y. Yao¹⁴, Y. Yasu⁶⁶,
 G.V. Ybeles Smit¹³⁰, J. Ye³⁹, S. Ye²⁴, M. Yilmaz^{3c}, R. Yoosoofmiya¹²³,
 K. Yorita¹⁷⁰, R. Yoshida⁵, C. Young¹⁴³, S. Youssef²¹, D. Yu²⁴, J. Yu⁷,
 J. Yu^{32c,ac}, L. Yuan^{32a,ad}, A. Yurkewicz¹⁴⁸, V.G. Zaets¹²⁸, R. Zaidan⁶³,
 A.M. Zaitsev¹²⁸, Z. Zajacova²⁹, Yo.K. Zalite¹²¹, L. Zanello^{132a,132b},
 P. Zarzhitsky³⁹, A. Zaytsev¹⁰⁷, C. Zeitnitz¹⁷⁴, M. Zeller¹⁷⁵, A. Zemla³⁸,

C. Zendler²⁰, A.V. Zenin¹²⁸, O. Zenin¹²⁸, T. Ženiš^{144a}, Z. Zenonos^{122a,122b}, S. Zenz¹⁴, D. Zerwas¹¹⁵, G. Zevi della Porta⁵⁷, Z. Zhan^{32d}, D. Zhang^{32b,aa}, H. Zhang⁸⁸, J. Zhang⁵, X. Zhang^{32d}, Z. Zhang¹¹⁵, L. Zhao¹⁰⁸, T. Zhao¹³⁸, Z. Zhao^{32b}, A. Zhemchugov⁶⁵, S. Zheng^{32a}, J. Zhong^{151,ae}, B. Zhou⁸⁷, N. Zhou¹⁶³, Y. Zhou¹⁵¹, C.G. Zhu^{32d}, H. Zhu⁴¹, Y. Zhu¹⁷², X. Zhuang⁹⁸, V. Zhuravlov⁹⁹, D. Zieminska⁶¹, R. Zimmermann²⁰, S. Zimmermann²⁰, S. Zimmermann⁴⁸, M. Ziolkowski¹⁴¹, R. Zitoun⁴, L. Živković³⁴, V.V. Zmouchko^{128,*}, G. Zobernig¹⁷², A. Zoccoli^{19a,19b}, Y. Zolnierowski⁴, A. Zsenei²⁹, M. zur Nedden¹⁵, V. Zutshi¹⁰⁶, L. Zwalinski²⁹.

- ¹ University at Albany, Albany NY, United States of America
- ² Department of Physics, University of Alberta, Edmonton AB, Canada
- ³ ^(a)Department of Physics, Ankara University, Ankara; ^(b)Department of Physics, Dumlupinar University, Kutahya; ^(c)Department of Physics, Gazi University, Ankara; ^(d)Division of Physics, TOBB University of Economics and Technology, Ankara; ^(e)Turkish Atomic Energy Authority, Ankara, Turkey
- ⁴ LAPP, CNRS/IN2P3 and Université de Savoie, Annecy-le-Vieux, France
- ⁵ High Energy Physics Division, Argonne National Laboratory, Argonne IL, United States of America
- ⁶ Department of Physics, University of Arizona, Tucson AZ, United States of America
- ⁷ Department of Physics, The University of Texas at Arlington, Arlington TX, United States of America
- ⁸ Physics Department, University of Athens, Athens, Greece
- ⁹ Physics Department, National Technical University of Athens, Zografou, Greece
- ¹⁰ Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan
- ¹¹ Institut de Física d'Altes Energies and Universitat Autònoma de Barcelona and ICREA, Barcelona, Spain
- ¹² ^(a)Institute of Physics, University of Belgrade, Belgrade; ^(b)Vinca Institute of Nuclear Sciences, Belgrade, Serbia
- ¹³ Department for Physics and Technology, University of Bergen, Bergen, Norway
- ¹⁴ Physics Division, Lawrence Berkeley National Laboratory and University of California, Berkeley CA, United States of America
- ¹⁵ Department of Physics, Humboldt University, Berlin, Germany
- ¹⁶ Albert Einstein Center for Fundamental Physics and Laboratory for High Energy Physics, University of Bern, Bern, Switzerland
- ¹⁷ School of Physics and Astronomy, University of Birmingham, Birmingham, United Kingdom
- ¹⁸ ^(a)Department of Physics, Bogazici University, Istanbul; ^(b)Division of Physics, Dogus University, Istanbul; ^(c)Department of Physics Engineering, Gaziantep University, Gaziantep; ^(d)Department of Physics, Istanbul Technical University, Istanbul, Turkey
- ¹⁹ ^(a)INFN Sezione di Bologna; ^(b)Dipartimento di Fisica, Università di Bologna, Bologna, Italy

- 20 Physikalisches Institut, University of Bonn, Bonn, Germany
- 21 Department of Physics, Boston University, Boston MA, United States of America
- 22 Department of Physics, Brandeis University, Waltham MA, United States of America
- 23 ^(a)Universidade Federal do Rio De Janeiro COPPE/EE/IF, Rio de Janeiro;
^(b)Instituto de Física, Universidade de Sao Paulo, Sao Paulo, Brazil
- 24 Physics Department, Brookhaven National Laboratory, Upton NY, United States of America
- 25 ^(a)National Institute of Physics and Nuclear Engineering, Bucharest; ^(b)University Politehnica Bucharest, Bucharest; ^(c)West University in Timisoara, Timisoara, Romania
- 26 Departamento de Física, Universidad de Buenos Aires, Buenos Aires, Argentina
- 27 Cavendish Laboratory, University of Cambridge, Cambridge, United Kingdom
- 28 Department of Physics, Carleton University, Ottawa ON, Canada
- 29 CERN, Geneva, Switzerland
- 30 Enrico Fermi Institute, University of Chicago, Chicago IL, United States of America
- 31 ^(a)Departamento de Física, Pontificia Universidad Católica de Chile, Santiago;
^(b)Departamento de Física, Universidad Técnica Federico Santa María, Valparaíso, Chile
- 32 ^(a)Institute of High Energy Physics, Chinese Academy of Sciences, Beijing;
^(b)Department of Modern Physics, University of Science and Technology of China, Anhui; ^(c)Department of Physics, Nanjing University, Jiangsu; ^(d)High Energy Physics Group, Shandong University, Shandong, China
- 33 Laboratoire de Physique Corpusculaire, Clermont Université and Université Blaise Pascal and CNRS/IN2P3, Aubiere Cedex, France
- 34 Nevis Laboratory, Columbia University, Irvington NY, United States of America
- 35 Niels Bohr Institute, University of Copenhagen, Kobenhavn, Denmark
- 36 ^(a)INFN Gruppo Collegato di Cosenza; ^(b)Dipartimento di Fisica, Università della Calabria, Arcavata di Rende, Italy
- 37 Faculty of Physics and Applied Computer Science, AGH-University of Science and Technology, Krakow, Poland
- 38 The Henryk Niewodniczanski Institute of Nuclear Physics, Polish Academy of Sciences, Krakow, Poland
- 39 Physics Department, Southern Methodist University, Dallas TX, United States of America
- 40 Physics Department, University of Texas at Dallas, Richardson TX, United States of America
- 41 DESY, Hamburg and Zeuthen, Germany
- 42 Institut für Experimentelle Physik IV, Technische Universität Dortmund, Dortmund, Germany
- 43 Institut für Kern- und Teilchenphysik, Technical University Dresden, Dresden, Germany
- 44 Department of Physics, Duke University, Durham NC, United States of America

- 45 SUPA - School of Physics and Astronomy, University of Edinburgh, Edinburgh,
United Kingdom
- 46 Fachhochschule Wiener Neustadt, Johannes Gutenbergstrasse 3 2700 Wiener
Neustadt, Austria
- 47 INFN Laboratori Nazionali di Frascati, Frascati, Italy
- 48 Fakultät für Mathematik und Physik, Albert-Ludwigs-Universität, Freiburg i.Br.,
Germany
- 49 section de Physique, Université de Genève, Geneva, Switzerland
- 50 ^(a)INFN Sezione di Genova; ^(b)Dipartimento di Fisica, Università di Genova,
Genova, Italy
- 51 Institute of Physics and HEP Institute, Georgian Academy of Sciences and Tbilisi
State University, Tbilisi, Georgia
- 52 II Physikalisches Institut, Justus-Liebig-Universität Giessen, Giessen, Germany
- 53 SUPA - School of Physics and Astronomy, University of Glasgow, Glasgow, United
Kingdom
- 54 II Physikalisches Institut, Georg-August-Universität, Göttingen, Germany
- 55 Laboratoire de Physique Subatomique et de Cosmologie, Université Joseph Fourier
and CNRS/IN2P3 and Institut National Polytechnique de Grenoble, Grenoble,
France
- 56 Department of Physics, Hampton University, Hampton VA, United States of
America
- 57 Laboratory for Particle Physics and Cosmology, Harvard University, Cambridge
MA, United States of America
- 58 ^(a)Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Heidelberg;
^(b)Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg;
^(c)ZITI Institut für technische Informatik, Ruprecht-Karls-Universität Heidelberg,
Mannheim, Germany
- 59 Faculty of Science, Hiroshima University, Hiroshima, Japan
- 60 Faculty of Applied Information Science, Hiroshima Institute of Technology,
Hiroshima, Japan
- 61 Department of Physics, Indiana University, Bloomington IN, United States of
America
- 62 Institut für Astro- und Teilchenphysik, Leopold-Franzens-Universität, Innsbruck,
Austria
- 63 University of Iowa, Iowa City IA, United States of America
- 64 Department of Physics and Astronomy, Iowa State University, Ames IA, United
States of America
- 65 Joint Institute for Nuclear Research, JINR Dubna, Dubna, Russia
- 66 KEK, High Energy Accelerator Research Organisation, Tsukuba, Japan
- 67 Graduate School of Science, Kobe University, Kobe, Japan
- 68 Faculty of Science, Kyoto University, Kyoto, Japan
- 69 Kyoto University of Education, Kyoto, Japan
- 70 Instituto de Física La Plata, Universidad Nacional de La Plata and CONICET, La
Plata, Argentina

- ⁷¹ Physics Department, Lancaster University, Lancaster, United Kingdom
- ⁷² ^(a)INFN Sezione di Lecce; ^(b)Dipartimento di Fisica, Università del Salento, Lecce, Italy
- ⁷³ Oliver Lodge Laboratory, University of Liverpool, Liverpool, United Kingdom
- ⁷⁴ Department of Physics, Jožef Stefan Institute and University of Ljubljana, Ljubljana, Slovenia
- ⁷⁵ Department of Physics, Queen Mary University of London, London, United Kingdom
- ⁷⁶ Department of Physics, Royal Holloway University of London, Surrey, United Kingdom
- ⁷⁷ Department of Physics and Astronomy, University College London, London, United Kingdom
- ⁷⁸ Laboratoire de Physique Nucléaire et de Hautes Energies, UPMC and Université Paris-Diderot and CNRS/IN2P3, Paris, France
- ⁷⁹ Fysiska institutionen, Lunds universitet, Lund, Sweden
- ⁸⁰ Departamento de Física Teórica C-15, Universidad Autónoma de Madrid, Madrid, Spain
- ⁸¹ Institut für Physik, Universität Mainz, Mainz, Germany
- ⁸² School of Physics and Astronomy, University of Manchester, Manchester, United Kingdom
- ⁸³ CPPM, Aix-Marseille Université and CNRS/IN2P3, Marseille, France
- ⁸⁴ Department of Physics, University of Massachusetts, Amherst MA, United States of America
- ⁸⁵ Department of Physics, McGill University, Montreal QC, Canada
- ⁸⁶ School of Physics, University of Melbourne, Victoria, Australia
- ⁸⁷ Department of Physics, The University of Michigan, Ann Arbor MI, United States of America
- ⁸⁸ Department of Physics and Astronomy, Michigan State University, East Lansing MI, United States of America
- ⁸⁹ ^(a)INFN Sezione di Milano; ^(b)Dipartimento di Fisica, Università di Milano, Milano, Italy
- ⁹⁰ B.I. Stepanov Institute of Physics, National Academy of Sciences of Belarus, Minsk, Republic of Belarus
- ⁹¹ National Scientific and Educational Centre for Particle and High Energy Physics, Minsk, Republic of Belarus
- ⁹² Department of Physics, Massachusetts Institute of Technology, Cambridge MA, United States of America
- ⁹³ Group of Particle Physics, University of Montreal, Montreal QC, Canada
- ⁹⁴ P.N. Lebedev Institute of Physics, Academy of Sciences, Moscow, Russia
- ⁹⁵ Institute for Theoretical and Experimental Physics (ITEP), Moscow, Russia
- ⁹⁶ Moscow Engineering and Physics Institute (MEPhI), Moscow, Russia
- ⁹⁷ Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia

- ⁹⁸ Fakultät für Physik, Ludwig-Maximilians-Universität München, München, Germany
⁹⁹ Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), München, Germany
¹⁰⁰ Nagasaki Institute of Applied Science, Nagasaki, Japan
¹⁰¹ Graduate School of Science, Nagoya University, Nagoya, Japan
¹⁰² ^(a)INFN Sezione di Napoli; ^(b)Dipartimento di Scienze Fisiche, Università di Napoli, Napoli, Italy
¹⁰³ Department of Physics and Astronomy, University of New Mexico, Albuquerque NM, United States of America
¹⁰⁴ Institute for Mathematics, Astrophysics and Particle Physics, Radboud University Nijmegen/Nikhef, Nijmegen, Netherlands
¹⁰⁵ Nikhef National Institute for Subatomic Physics and University of Amsterdam, Amsterdam, Netherlands
¹⁰⁶ Department of Physics, Northern Illinois University, DeKalb IL, United States of America
¹⁰⁷ Budker Institute of Nuclear Physics (BINP), Novosibirsk, Russia
¹⁰⁸ Department of Physics, New York University, New York NY, United States of America
¹⁰⁹ Ohio State University, Columbus OH, United States of America
¹¹⁰ Faculty of Science, Okayama University, Okayama, Japan
¹¹¹ Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman OK, United States of America
¹¹² Department of Physics, Oklahoma State University, Stillwater OK, United States of America
¹¹³ Palacký University, RCPTM, Olomouc, Czech Republic
¹¹⁴ Center for High Energy Physics, University of Oregon, Eugene OR, United States of America
¹¹⁵ LAL, Univ. Paris-Sud and CNRS/IN2P3, Orsay, France
¹¹⁶ Graduate School of Science, Osaka University, Osaka, Japan
¹¹⁷ Department of Physics, University of Oslo, Oslo, Norway
¹¹⁸ Department of Physics, Oxford University, Oxford, United Kingdom
¹¹⁹ ^(a)INFN Sezione di Pavia; ^(b)Dipartimento di Fisica Nucleare e Teorica, Università di Pavia, Pavia, Italy
¹²⁰ Department of Physics, University of Pennsylvania, Philadelphia PA, United States of America
¹²¹ Petersburg Nuclear Physics Institute, Gatchina, Russia
¹²² ^(a)INFN Sezione di Pisa; ^(b)Dipartimento di Fisica E. Fermi, Università di Pisa, Pisa, Italy
¹²³ Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh PA, United States of America
¹²⁴ ^(a)Laboratorio de Instrumentacao e Fisica Experimental de Particulas - LIP, Lisboa, Portugal; ^(b)Departamento de Fisica Teorica y del Cosmos and CAFPE, Universidad de Granada, Granada, Spain
¹²⁵ Institute of Physics, Academy of Sciences of the Czech Republic, Praha, Czech Republic

- 126 Faculty of Mathematics and Physics, Charles University in Prague, Praha, Czech Republic
- 127 Czech Technical University in Prague, Praha, Czech Republic
- 128 State Research Center Institute for High Energy Physics, Protvino, Russia
- 129 Particle Physics Department, Rutherford Appleton Laboratory, Didcot, United Kingdom
- 130 Physics Department, University of Regina, Regina SK, Canada
- 131 Ritsumeikan University, Kusatsu, Shiga, Japan
- 132 ^(a)INFN Sezione di Roma I; ^(b)Dipartimento di Fisica, Università La Sapienza, Roma, Italy
- 133 ^(a)INFN Sezione di Roma Tor Vergata; ^(b)Dipartimento di Fisica, Università di Roma Tor Vergata, Roma, Italy
- 134 ^(a)INFN Sezione di Roma Tre; ^(b)Dipartimento di Fisica, Università Roma Tre, Roma, Italy ¹³⁵ ^(a)Faculté des Sciences Ain Chock, Réseau Universitaire de Physique des Hautes Energies - Université Hassan II, Casablanca; ^(b)Centre National de l'Énergie des Sciences Techniques Nucleaires, Rabat; ^(c)Université Cadi Ayyad, Faculté des sciences Semlalia Département de Physique, B.P. 2390 Marrakech 40000; ^(d)Faculté des Sciences, Université Mohamed Premier and LPTPM, Oujda; ^(e)Faculté des Sciences, Université Mohammed V, Rabat, Morocco
- 136 DSM/IRFU (Institut de Recherches sur les Lois Fondamentales de l'Univers), CEA Saclay (Commissariat à l'Énergie Atomique), Gif-sur-Yvette, France
- 137 Santa Cruz Institute for Particle Physics, University of California Santa Cruz, Santa Cruz CA, United States of America
- 138 Department of Physics, University of Washington, Seattle WA, United States of America
- 139 Department of Physics and Astronomy, University of Sheffield, Sheffield, United Kingdom
- 140 Department of Physics, Shinshu University, Nagano, Japan
- 141 Fachbereich Physik, Universität Siegen, Siegen, Germany
- 142 Department of Physics, Simon Fraser University, Burnaby BC, Canada
- 143 SLAC National Accelerator Laboratory, Stanford CA, United States of America
- 144 ^(a)Faculty of Mathematics, Physics & Informatics, Comenius University, Bratislava; ^(b)Department of Subnuclear Physics, Institute of Experimental Physics of the Slovak Academy of Sciences, Kosice, Slovak Republic
- 145 ^(a)Department of Physics, University of Johannesburg, Johannesburg; ^(b)School of Physics, University of the Witwatersrand, Johannesburg, South Africa
- 146 ^(a)Department of Physics, Stockholm University; ^(b)The Oskar Klein Centre, Stockholm, Sweden
- 147 Physics Department, Royal Institute of Technology, Stockholm, Sweden
- 148 Department of Physics and Astronomy, Stony Brook University, Stony Brook NY, United States of America
- 149 Department of Physics and Astronomy, University of Sussex, Brighton, United Kingdom

- 150 School of Physics, University of Sydney, Sydney, Australia
- 151 Institute of Physics, Academia Sinica, Taipei, Taiwan
- 152 Department of Physics, Technion: Israel Inst. of Technology, Haifa, Israel
- 153 Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv, Israel
- 154 Department of Physics, Aristotle University of Thessaloniki, Thessaloniki, Greece
- 155 International Center for Elementary Particle Physics and Department of Physics, The University of Tokyo, Tokyo, Japan
- 156 Graduate School of Science and Technology, Tokyo Metropolitan University, Tokyo, Japan
- 157 Department of Physics, Tokyo Institute of Technology, Tokyo, Japan
- 158 Department of Physics, University of Toronto, Toronto ON, Canada
- 159 ^(a)TRIUMF, Vancouver BC; ^(b)Department of Physics and Astronomy, York University, Toronto ON, Canada
- 160 Institute of Pure and Applied Sciences, University of Tsukuba, Ibaraki, Japan
- 161 Science and Technology Center, Tufts University, Medford MA, United States of America
- 162 Centro de Investigaciones, Universidad Antonio Narino, Bogota, Colombia
- 163 Department of Physics and Astronomy, University of California Irvine, Irvine CA, United States of America
- 164 ^(a)INFN Gruppo Collegato di Udine; ^(b)ICTP, Trieste; ^(c)Dipartimento di Fisica, Università di Udine, Udine, Italy
- 165 Department of Physics, University of Illinois, Urbana IL, United States of America
- 166 Department of Physics and Astronomy, University of Uppsala, Uppsala, Sweden
- 167 Instituto de Física Corpuscular (IFIC) and Departamento de Física Atómica, Molecular y Nuclear and Departamento de Ingeniería Electrónica and Instituto de Microelectrónica de Barcelona (IMB-CNM), University of Valencia and CSIC, Valencia, Spain
- 168 Department of Physics, University of British Columbia, Vancouver BC, Canada
- 169 Department of Physics and Astronomy, University of Victoria, Victoria BC, Canada
- 170 Waseda University, Tokyo, Japan
- 171 Department of Particle Physics, The Weizmann Institute of Science, Rehovot, Israel
- 172 Department of Physics, University of Wisconsin, Madison WI, United States of America
- 173 Fakultät für Physik und Astronomie, Julius-Maximilians-Universität, Würzburg, Germany
- 174 Fachbereich C Physik, Bergische Universität Wuppertal, Wuppertal, Germany
- 175 Department of Physics, Yale University, New Haven CT, United States of America
- 176 Yerevan Physics Institute, Yerevan, Armenia
- 177 Domaine scientifique de la Doua, Centre de Calcul CNRS/IN2P3, Villeurbanne Cedex, France
- ^a Also at Laboratório de Instrumentação e Física Experimental de Partículas - LIP, Lisboa, Portugal

- ^b Also at Faculdade de Ciencias and CFNUL, Universidade de Lisboa, Lisboa, Portugal
- ^c Also at Particle Physics Department, Rutherford Appleton Laboratory, Didcot, United Kingdom
- ^d Also at CPPM, Aix-Marseille Université and CNRS/IN2P3, Marseille, France
- ^e Also at TRIUMF, Vancouver BC, Canada
- ^f Also at Department of Physics, California State University, Fresno CA, United States of America
- ^g Also at Faculty of Physics and Applied Computer Science, AGH-University of Science and Technology, Krakow, Poland
- ^h Also at Department of Physics, University of Coimbra, Coimbra, Portugal
- ⁱ Also at Università di Napoli Parthenope, Napoli, Italy
- ^j Also at Institute of Particle Physics (IPP), Canada
- ^k Also at Department of Physics, Middle East Technical University, Ankara, Turkey
- ^l Also at Louisiana Tech University, Ruston LA, United States of America
- ^m Also at Group of Particle Physics, University of Montreal, Montreal QC, Canada
- ⁿ Also at Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan
- ^o Also at Institut für Experimentalphysik, Universität Hamburg, Hamburg, Germany
- ^p Also at Manhattan College, New York NY, United States of America
- ^q Also at School of Physics and Engineering, Sun Yat-sen University, Guanzhou, China
- ^r Also at Academia Sinica Grid Computing, Institute of Physics, Academia Sinica, Taipei, Taiwan
- ^s Also at High Energy Physics Group, Shandong University, Shandong, China
- ^t Also at California Institute of Technology, Pasadena CA, United States of America
- ^u Also at section de Physique, Université de Genève, Geneva, Switzerland
- ^v Also at Departamento de Física, Universidade de Minho, Braga, Portugal
- ^w Also at Department of Physics and Astronomy, University of South Carolina, Columbia SC, United States of America
- ^x Also at KFKI Research Institute for Particle and Nuclear Physics, Budapest, Hungary
- ^y Also at Institute of Physics, Jagiellonian University, Krakow, Poland
- ^z Also at Department of Physics, Oxford University, Oxford, United Kingdom
- ^{aa} Also at Institute of Physics, Academia Sinica, Taipei, Taiwan
- ^{ab} Also at Department of Physics, The University of Michigan, Ann Arbor MI, United States of America
- ^{ac} Also at DSM/IRFU (Institut de Recherches sur les Lois Fondamentales de l'Univers), CEA Saclay (Commissariat à l'Énergie Atomique), Gif-sur-Yvette, France
- ^{ad} Also at Laboratoire de Physique Nucléaire et de Hautes Energies, UPMC and Université Paris-Diderot and CNRS/IN2P3, Paris, France
- ^{ae} Also at Department of Physics, Nanjing University, Jiangsu, China
- * Deceased